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USAAVLABS TECHNICAL REPORT 70-1A

HELICOPTER ROTOR ROTATIONAL NOISE PREDICTION AND CORRELATION

VOLUME I

ROTATIONAL NOISE PREDICTION AND CORRELATION UNDER NONUNIFORM INFLOW CONDITIONS

By

Ronald G. Schlegel

William E. Bausch

November 1970

U. S. ARMY AVIATION MATERIEL LABORATORIES FORT EUSTIS, VIRGINIA

CONTRACT DA 44-177-AMC-448(T)
SIKORSKY AIRCRAFT
DIVISION OF UNITED AIRCRAFT CORPORATION
STRATFORD, CONNECTICUT

105

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DEPARTMENT OF THE ARMY
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FORT EUSTIS, VIRGINIA 23604

This contract was initiated to acquire NH-3A/S-61F helicopter noise measurements simultaneously with low- and high-frequency aerodynamic rotor loads for the purpose of verifying the accuracy of a rotational noise prediction program. The program itself was modified from the previously assumed rectangular chordal airload distribution to the actual measured chordal airload distribution or to any arbitrary chordal distribution that the program user wished to assume.

Results of this contract demonstrate the importance of high-frequency airloads and the chordal airload distribution in rotational noise predictions. Although inconclusive regarding how many loading harmonics are necessary, findings do show that knowledge of the chordal airload distribution can compensate for a lack of high-frequency airload data.

There are a few available analytical solutions to helicopter rotational noise in addition to that reported herein. These analyses vary in rigor of approach, degree of difficulty of usage, and quantity of input data required, but all appear to be uniformly accurate for the first three or four harmonics of rotational noise under the few normal rotor operating conditions examined.

A program is currently under way to: (1) simultaneously acquire noise and rotor airloads data for "slapping" and "nonslapping" flight conditions of a CH-53A helicopter and (2) correlate these data with noise and airloads prediction methods. The acoustic analyses presented herein will be modified and used in an attempt to predict the occurrence of impulsive rotor noise.

Task 1F162203A14801
Contract DA 44-177-AMC-448(T)
USAAVLABS Technical Report 70-1A
November 1970

HELICOPTER ROTOR ROTATIONAL NOISE PREDICTION AND CORRELATION

Final Report

Volume I

ROTATIONAL NOISE PREDICTION AND CORRELATION UNDER NONUNIFORM INFLOW CONDITIONS

By

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For

U. S. ARMY AVIATION MATERIEL LABORATORIES
FORT EUSTIS, VIRGINIA

ABSTRACT

The results of a measurement, prediction, and correlation study of rotational noise of the Sikorsky NH-3A compound helicopter are presented in this report. Differential rotor blade pressures were measured in flight, and noise data were recorded simultaneously on the ground. In addition, the acoustic analysis developed under Contract DA 44-177-AMC-141(T) (Reference 1) was modified to accept higher harmonics of airload and the measured (or any arbitrary) chordwise distribution of airload. The measured differential pressures were then used as input to the analysis to calculate rotor rotational noise for comparison with measured levels.

Measured and predicted levels showed good correlation for the first four harmonics of noise during forward flight. Harmonics above the fourth were masked by jet engine exhaust noise and tail rotor noise. The correlation study demonstrated that the higher harmonics of airload and the chordwise distribution of pressure acting on the rotor blades are important for defining rotational noise levels and directional characteristics. Predicted levels grossly underestimated the levels measured during low-altitude hover. Acoustic directionality, near-field, and aerodynamic ground effects are considered to be responsible for the discrepancy.

The applicability of the acoustic analyses to impulsive rotor noise could not be determined from available data. Helicopter altitude and field-point placement required for prediction accuracy during hover have not been defined. Both of the preceding areas require additional study, as does the effect on correlation of including rotor orientation and translational motion terms in the acoustic analyses.

FOREWORD

A program of rotational noise prediction and correlation was conducted by Sikorsky Aircraft, Division of United Aircraft Corporation, under Contract DA 44-177-AMC-448(T), Task 1F162203A14801. USAAVLABS Project Engineer was Mr. Joseph H. McGarvey. The study was initiated on 27 June 1966 and completed on 31 May 1968. The results of this study are documented in a two-volume report.

This volume describes the rotational noise measurement, prediction, and correlation work that was done. Volume II describes the noise prediction computer program that was developed during the study.

Acknowledgement is made to Mr. John J. DeFelice for the data acquisition and reduction; to Mr. Harold R. Mull, of H. R. Mull and Associates, for his help and guidance in compiling and presenting the data; and to Mr. Moshe Richman for helping to develop the noise prediction analysis.

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LIST OF SYMBOLS

a	blade chord; inches
b	blade thickness; inches
c	speed of sound; inches per second
dB	decibel; referenced 0.0002 dyne/square centimeter
$\vec{F}$	force per unit volume, restricted to rotor disc; pounds per cubic inch
f	frequency; Hertz (cycles per second)
$\vec{g},\vec{h}$	Fourier coefficients of pressure profile
Hz	Hertz
$\vec{L}$	differential pressure; pounds per square inch
m	harmonic order
n	number of blades
P_m	sound pressure of mth harmonic
r	distance from center of rotation to a point in the rotor disc; inches
r_o	distance from center of rotation at which blade twist begins; inches
R	radius of rotor system; inches
s	distance from element of rotor disc to a field point; inches
SPL	sound pressure level; decibels
t	time; seconds
T	period of pressure pulse; seconds
τ	duration of pressure pulse; seconds
$x,y,z,$	Cartesian coordinates; inches
β	blade pitch angle; radians
γ	blade twist rate; radians per inch of span

LIST OF SYMBOLS

ψ	azimuth angle; radians
Ω	rotor rotational velocity; radians per second
ω	blade passage frequency, $n\Omega$; radians per second
σ	elevation angle; radians

INTRODUCTION

This report describes a program of rotational noise measurement and prediction using the NH-3A compound helicopter shown in Figure 1. The present program is a continuation of a study sponsored by U. S. Army Aviation Materiel Laboratories (Reference 1) which developed an analytical method for predicting rotational noise levels based on airload data. Results of this early work suggested that high-frequency components of airload contribute significantly to the higher harmonics of rotational noise. Consequently, the present program was initiated to evaluate the effect of high-frequency airloading on predicted rotational noise levels. Additional objectives were to evaluate the accuracy of the acoustic analysis for medium- and high-speed forward flight conditions and to modify the analysis if correlation between measured and predicted noise levels was unsatisfactory.

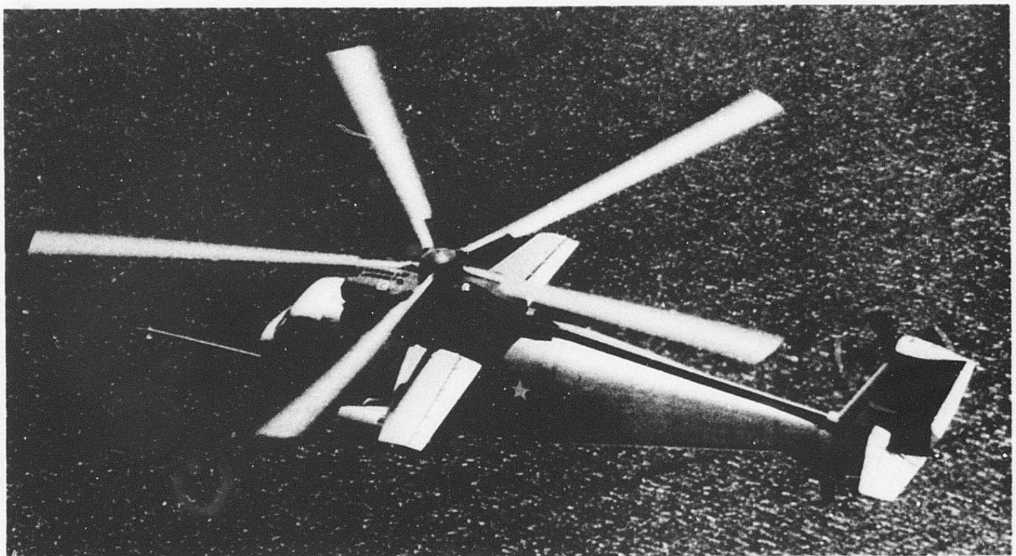


Figure 1. NH-3A Compound Helicopter.

The method for rotational noise prediction developed under Reference 1 is much more accurate for calculating harmonics of helicopter rotor noise than Gutin's method (Reference 2). Where Gutin's method considers a steady load concentrated at one point on the blade, Reference 1 considers oscillatory loads (up to 10 per rotor revolution) and distributes those loads along the length of the blade. This latter approach improves correlation for all harmonics of rotor noise, but the absolute correlation for the third and higher harmonics remains unsatisfactory. One way to improve this correlation is to consider higher frequency airloads. Additional improvement can be expected by including the chordwise distribution of airload on the rotor blades, as discussed by Watkins and Durling (Reference 3).

The present study used both techniques in refining the analysis developed in Reference 1. A new computer program was developed to calculate

rotational noise levels based on up to 30 harmonics of airload and the measured chordwise distribution of airload. In addition, calculations can be done with either 10 or 20 radial stations in order to define interference and reinforcement due to phasing in the rotor disc. The details of the computer program are contained in Volume II of this report. Noise due to aerodynamic shears and blade thickness is not considered in the present analysis. Distortion of the sound field due to translational motion of the noise source also has been neglected.

CALCULATION OF ROTATIONAL NOISE

INPUT DATA

Harmonics of differential pressure and blade pitch angle are used as basic input to the noise prediction computer program. When noise levels are calculated from the measured chordwise loading distribution, 30 harmonics of differential pressure are used as input at each transducer location on the rotor blades. When the hypothetical rectangular distribution is used, the harmonics of pressure are converted to harmonics of blade section loading. This is done by integrating the pressures across the blade chord at each blade location azimuth and performing a Fourier analysis of the resultant section loading as a function of azimuth angle. A trapezoidal-rule routine is used to perform the chordwise integration, and the Fourier analysis generates 30 harmonics of section loading. Appendix IV and Reference 4 describe the instrumentation and techniques used to record and process the raw aerodynamic data. Appendix V contains the harmonics of differential pressure for each span and chord location on the rotor blades. The aircraft trim settings and approximate wing lift, rotor thrust, and auxiliary jet engine thrust also are tabulated in Appendix V.

CALCULATION PROCEDURE

Calculated noise levels are based on either the measured chordwise loading distribution or the hypothetical rectangular distribution, or both, depending on the program option, for all flight conditions. Each cycle of pressure recorded from each transducer is divided into 144 points (145 if both the 0-degree and 360-degree azimuth positions are included). Consequently, the sampling rate is more than 4 times the highest airload frequency considered, and good definition of all harmonics of airload is assured. The noise analysis constructs an average pressure cycle for each pressure transducer on the blade from 10 consecutive cycles of data, and this average cycle then is used to define the harmonics of pressure and section loading. This series of pressures along the blade forms an array of stationary dipole acoustic sources in the rotor disc. These are converted to a net acoustic signal by application of the wave equation and integration over the disc.

DERIVATION OF MODIFIED NOISE PREDICTION EQUATIONS

The modified acoustic analysis retains many of the assumptions of the original (Reference 1) analysis. The rotor disc is assumed to be flat and parallel to the ground. The pressure fluctuations on the rotor disc are represented by stationary acoustics dipoles which radiate continuously at integral multiples of the rotor rotational frequency. At any radial and azimuthal position (r, ψ) in the rotor disc, the net contribution of the dipoles at (r, ψ) is the time history of pressure over that point. Figure 2 shows these periodic pressure variations at (r, ψ) and the rectangular approximation used in Reference 1. The modified analysis removes this assumption by using the actual chordal profile of differential pressure.

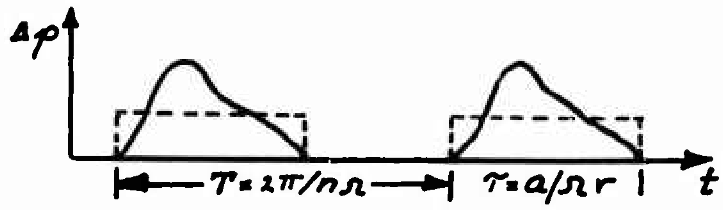


Figure 2. Periodic Pressure Variations and Rectangular Approximation at a Point in the Rotor Disc.

Mathematical Formulation

The differential equation of a pressure wave caused by a driving force is given in Reference 2 as

$$\left(\nabla^2 + k^2\right) p = \nabla \cdot \vec{F} \tag{1}$$

where $\vec{F}$ = force per unit volume

$k = \dfrac{mn\Omega}{c}$

m = 1, 2, 3, ..., harmonic order

n = number of rotor blades

Ω = rotor rotational velocity

p = pressure, or force per unit area

c = speed of sound

Equation (1) is equivalent to Equation (9) of Reference 1 for simple harmonic oscillations. Reference 10, Sections 287 through 291, contains the details of the relationship.

The force $\vec{F}$ varies in a periodic fashion with time t and can be represented by the following Fourier series for any point in the rotor disc:

$$\vec{F}(r,\psi,t) = \sum_{m=0}^{\infty} \left[\vec{g}_m(r,\psi) \cos mn\Omega t + \vec{h}_m(r,\psi) \sin mn\Omega t \right] \tag{2}$$

$\vec{F}$ is related to the differential pressure $\vec{T}$ acting on a rotor blade element at (r, ψ) and time t by the expression

$$\vec{F}(r,\psi,t) = \frac{1}{b} \vec{T}(r,\psi,t) \tag{3}$$

where b = blade thickness

Substituting this into (2) yields

$$\frac{1}{b}\vec{L}(r,\psi,t) = \sum_{m=0}^{\infty}\left[\vec{g_m}(r,\psi)\cos m\omega t + \vec{h_m}(r,\psi)\sin m\omega t\right] \tag{4}$$

Appendix I transforms Equation (4) from time to space variables and solves for $\vec{g_m}$ and $\vec{h_m}$. The phasing caused by rotation of the blades changes (t) to $(t-\frac{\psi}{\Omega})$ in Equation (4), so that

$$\vec{F}(r,\psi,t) = \frac{n}{\pi b}\sum_{m=1}^{\infty}\left[\int_{-a/2r}^{a/2r}\vec{L}(r,\psi)\cos mn\psi\, d\psi \cos m\omega(t-\frac{\psi}{\Omega})\right.$$

$$\left. + \int_{-a/2r}^{a/2r}\vec{L}(r,\psi)\sin mn\psi\, d\psi \sin m\omega(t-\frac{\psi}{\Omega})\right] \tag{5}$$

The components of the $\vec{g_m}$ and $\vec{h_m}$ coefficients in Cartesian coordinates with the origin at the center of rotation are, from Figures 3 and 4,

$$\begin{aligned} g_{mx} &= g_m \sin\beta \sin\psi & h_{mx} &= h_m \sin\beta \sin\psi \\ g_{my} &= -g_m \sin\beta \cos\psi & h_{my} &= -h_m \sin\beta \cos\psi \\ g_{mz} &= g_m \cos\beta & h_{mz} &= h_m \cos\beta \end{aligned} \tag{6}$$

A solution to Equation (1) for the mth harmonic of sound pressure P at a point (x, y, z) and time t can be derived from Reference 2 as:

$$P_m(x,y,z,t) = \frac{1}{4\pi}\int_0^{2\pi}\int_0^R\int_0^b\left[\left(g_{mx}\frac{\partial}{\partial x} + g_{my}\frac{\partial}{\partial y} + g_{mz}\frac{\partial}{\partial z}\right)\frac{\cos mn\Omega(t-\frac{\psi}{\Omega}-\frac{s}{c})}{s}\right.$$

$$\left. + \left(h_{mx}\frac{\partial}{\partial x} + h_{my}\frac{\partial}{\partial y} + h_{mz}\frac{\partial}{\partial z}\right)\frac{\sin mn\Omega(t-\frac{\psi}{\Omega}-\frac{s}{c})}{s}\right] db\, dr\, r d\psi \tag{7}$$

where the volume integral is over the rotor disc of thickness h, radius R, and swept azimuth 2π. This solution assumes spherical radiation with a boundary at infinity, but for practical applications it is sufficient for the helicopter to be out of ground effect (approximately 2 rotor diameters above the ground). The term s is the distance from an element $dr, r d\psi$ in the rotor disc centered over the point (r, ψ) to a field point (x, y, z) as shown in Figure 3. The term s/c accounts for the relative phasing of the elements due to variations in distance from each (r, ψ) to the field point (x, y, z).

The basic equation for s is

$$s = \left[(x - x_0)^2 + (y - y_0)^2 + (z - z_0)^2 \right]^{\frac{1}{2}} \tag{8a}$$

which becomes

$$s = \left[(x - r\cos\psi)^2 + (y - r\sin\psi)^2 + z^2 \right]^{\frac{1}{2}} \tag{8b}$$

when the origin is taken at the center of the rotor disc.

The derivatives and products of Equation (7) are evaluated in Appendix II. Integrating Equation (7) over db, substituting Equation (6) for the components of $\overrightarrow{g_m}$ and h_m, and factoring the term

$$q_1 \equiv (x - r\cos\psi)\sin\beta\,\sin\psi - (y - r\sin\psi)\sin\beta\,\cos\psi + z\cos\beta \tag{9}$$

results in

$$P_m(x,y,z,t) = \frac{b}{4\pi}\int_0^{2\pi}\int_0^{R} q_1(x,y,z,\psi)\Bigg\{ g_m\left[-\frac{\cos mn\Omega(t - \frac{\psi}{\Omega} - \frac{s}{c})}{s^3} + \frac{mn\Omega\,\sin mn\Omega(t - \frac{\psi}{\Omega} - \frac{s}{c})}{cs^2} \right] + h_m\left[-\frac{\sin mn\Omega(t - \frac{\psi}{\Omega} - \frac{s}{c})}{s^3} - \frac{mn\Omega\,\cos mn\Omega(t - \frac{\psi}{\Omega} - \frac{s}{c})}{cs^2} \right]\Bigg\}\, r\,dr\,d\psi \tag{10}$$

Expansion of the trigonometric terms in (10) by means of the identities

$$\cos(a - \phi) = \cos a\,\cos\phi + \sin a\,\sin\phi$$

$$\sin(a - \phi) = \sin a\,\cos\phi - \cos a\,\sin\phi \tag{11}$$

where

$$a = mn\Omega t$$

$$\phi = mn\Omega\left(\frac{\psi}{\Omega} + \frac{s}{c}\right)$$

permits identification of the following factors:

$$q_2 \equiv g_m\left(\frac{-\cos\phi}{s^3} - \frac{mn\Omega}{cs^2}\sin\phi\right) + h_m\left(\frac{\sin\phi}{s^3} - \frac{mn\Omega}{cs^2}\cos\phi\right) \qquad (12a)$$

and

$$q_3 \equiv g_m\left(\frac{-\sin\phi}{s^3} + \frac{mn\Omega}{cs^2}\cos\phi\right) + h_m\left(\frac{-\cos\phi}{s^3} - \frac{mn\Omega}{cs^2}\sin\phi\right) \qquad (12b)$$

Equations (9) and (12) combine to define the terms

$$u_m = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{r_t} b\, q_1 q_2\, r\, dr\, d\psi$$

$$v_m = \frac{1}{4\pi}\int_0^{2\pi}\int_0^{r_t} b\, q_1 q_3\, r\, dr\, d\psi \qquad (13)$$

Equation (10) then can be rewritten in shorter form by using Equations (13):

$$P_m(x,y,z,t) = u_m \cos mn\Omega t + v_m \sin mn\Omega t \qquad (14)$$

Equation (14) defines the time history of the mth harmonic of acoustic pressure at a field point (x, y, z). The root-mean-square (rms) pressure is now calculated to facilitate comparison of theory with experiment:

$$P_{m_{rms}}(x,y,z) = \frac{1}{\sqrt{2}}\sqrt{u_m^2 + v_m^2} \qquad (15)$$

It is convenient to express the final result for the m th noise harmonic in terms of sound pressure level (SPL) in decibels (dB) referenced to .0002 dyne/square centimeter:

$$SPL_m = 20 \log\left(\frac{P_{m_{rms}}}{2.9\times10^{-9}}\right) \qquad (16)$$

The preceding equations have been programmed in FORTRAN V for the UNIVAC 1108 digital computing system. Appendix III describes the computer program.

CORRELATION OF ROTATIONAL NOISE

DISCUSSION

Predicted and measured noise levels are compared on the basis of (SPL) versus helicopter location relative to the noise measurement station. As plotted in Figures 5 through 8, comparison of measured and calculated levels is based on aircraft location when the sound is generated by the rotor. The difference in aircraft location between the time that the noise is generated and the time that it arrives at the recording station has been compensated for in the measured data. An additional note is required about the coordinate axes indicated on Figures 5 through 8. The origin of the small axes indicated on these figures coincides with the location of an observer. X, Y, and Z locate the helicopter rotor relative to this observer. In Figure 3, the origin is the rotor hub and the coordinates locate an observer relative to the rotor. For Figures 5 through 8, positive Z means the rotor is above the observer, and positive X means the rotor is flying away from the observer. Positive Y is defined to form a right-handed Cartesian coordinate system.

Only the first four noise harmonics are considered for correlation. Tail rotor rotational noise and auxiliary jet engine noise made it impossible to isolate the higher noise harmonics with available data reduction equipment. The narrow-band (8%) plot in Figure 9 shows the masking of the main rotor harmonics above the fourth. Appendix VI describes the acoustic instrumentation and data reduction techniques.

Forward Flight

Correlation is good for the first four harmonics of measured and predicted rotational noise during forward flight. Figures 5 and 6 compare measured and predicted levels for the 165-knot flight conditions, and Figures 7 and 8 compare levels for the 190-knot conditions. One salient feature of the correlation is that the agreement for the fourth harmonic is generally as good as the agreement for the lower harmonics, while Reference 1 found that correlation deteriorated rapidly for the third and fourth harmonics. The main reason behind this improved higher harmonic correlation is the availability of high-frequency airload data. Where some previous investigations were limited to the 10 loading harmonics presented in Reference 5, the present study had 30 harmonics from full-scale flight data. An additional contributor to the improved correlation is the simultaneous measurement of both aerodynamic and acoustic data.

Another interesting aspect of the correlation is the apparent lack of effect of forward speed. The noise prediction equations contain the simplifying assumption of stationary dipoles radiating into a stationary medium; <u>i.e.</u>, ideal hover conditions. Reference 1 concludes that the equations should yield satisfactory results for translational Mach numbers below 0.3, which is close to the Mach number attained at 190 knots. The correlation obtained here confirms the applicability of the noise prediction equations for speeds up to 190 knots.

Correlation is poor for the second harmonic of the 165-knot high-wing-lift

flight condition (Figure 5b). Rotor orientation, aircraft velocity, and aerodynamic input data are possible explanations of the discrepancy between predicted and measured levels. The effects of rotor orientation are considered to be secondary since correlation for the other harmonics at this flight condition is acceptable. The inclusion of rotor orientation - rigid-body blade flapping and coning - in the prediction analysis probably would influence correlation by a few dB, but the orientation effects are not likely to account for the discrepancy shown in Figure 5b. Forward aircraft velocity is discounted in this case because correlation at the higher airspeed is good. To check the effect of changing cycles of aerodynamic pressure data, noise levels were recalculated using four consecutive but new pressure cycles as the basis for the average cycle at each transducer location. A comparison of the spectra in Figure 10 shows a correlation improvement in the second harmonic of 9 dB for the actual chordwise loading and 15 dB for the rectangular chordwise loading due to the new pressure data. This is a graphic example of the variations in rotor blade environment that can occur during straight and level flight through fairly calm air. The poor correlation in Figure 5b indicates that the pressure cycles originally used to calculate the noise levels do not represent the rotor environment that produced the measured noise.

Hover

Correlation for the hover case is poor, as shown in Figure 11a. This result is surprising after the good forward flight correlation obtained in this study and the good out-of-ground-effect hover correlation reported in Reference 1. A thorough study of the hover case revealed that the poor correlation is caused by operation in ground effect (IGE). The agreement between measured and predicted spectrum shapes in Figure 11b could be mere coincidence.

No malfunctions could be found in the noise prediction computer program, and the aerodynamic pressure data appear to be reasonable both in magnitude and in harmonic content. Acoustic data show no signs of the recorder's being overloaded, and the attenuator settings on the sound level meter are documented correctly. Therefore, the poor correlation is not caused by any identifiable error.

The following factors are considered to be responsible for the disagreement between predicted and measured levels.

Boundary Conditions

The NH-3A hovered with its landing gear approximately 10 feet above the runway, as shown in Figure 12. The proximity of the ground changed the radiation from spherical to hemispherical spreading. Levels from a source radiating hemispherically will be 3 dB higher than levels from the same source radiating spherically. Since the analysis assumes spherical radiation (boundaries at infinity), accurately predicted levels would be expected to be 3 dB lower than measured levels.

Near-Field Effects

Significant variations in the noise signal were observed at the noise measurement location, indicating that measurements were being made within the acoustic near field of the helicopter. Whirl stand and hover noise data from a rotor farther above the ground have shown that measurements taken at 250 feet normally are in the far field (6 dB attenuation per doubling of source-to-observer distance), and the noise prediction analysis predicts this attenuation at 250 feet. This means that the near-field terms of the analysis are negligible at this distance. For the NH-3A hover IGE, the near-field effects apparently were dominant rather than negligible because of the enlarged near field. The presence of near-field terms in the analysis commensurate with the requirements of the test environment would increase predicted levels substantially, thereby decreasing the discrepancy between measured and predicted noise levels.

Pseudosound

Pseudosound is the response of a microphone to any pressure fluctuations within the flow field that propagate at the mean velocity of the flow rather than at the speed of sound. References 6 and 7 discuss pseudosound in detail. Considerable turbulence from the rotor downwash was observed at the noise measurement station, and this turbulence undoubtedly added pseudosound to the actual rotor noise signal. Since the trailing vortices from each blade tip will move rapidly downward and outward close to the ground, the pseudosound conceivably could augment rotational noise harmonic levels since the filaments in the trailing vortex system would have to pass the microphone at the blade passage frequency.

Directivity

The noise analysis predicts the usual directivity pattern for a rotor or propeller, with a pronounced pressure minimum occurring near the plane of the rotor and a principal maximum below the rotor, as illustrated in Figure 13. Such a sharp pattern rarely is measured because of phasing variations and unsteady phenomena that occur in a practical situation. The field point selected for hover correlation - 250 feet in front of the helicopter and 15 feet below the plane of the rotor - is in an area of rapid change of the predicted SPL. It is certainly reasonable to expect that the actual directivity pattern will be less clearly defined than the predicted pattern, especially with the severe turbulence and flow recirculation encountered during operation so close to the ground.

The hover measurements were made at low altitude to insure that the hover survey would detect the azimuthal variations in SPL around the helicopter. Polar plots of the SPL in each octave band are presented in Figure 14 for the hover condition. Note that there are several points at which the faired curves do not pass through the symbols. The curves pass through the measured SPL every 30 degrees of azimuth; the symbols are offset to

preserve legibility at points where the levels in adjacent octave bands are equal.

The problems encountered here are reminiscent of those reported by Loewy and Sutton (Reference 8) in that their predicted levels were much lower than measured CH-34 levels during hover IGE. An experimental study should be made of the acoustical and aerodynamic transitions that occur between hover OGE and IGE in order to check the preceding explanations.

CORRELATION SUMMARY

Predicted and measured rotational noise levels correlate quite well through the fourth harmonic during forward flight. Forward velocity has no noticeable effect on the correlation obtained during this study. Variations in blade pressure data from cycle to cycle in any given flight condition can cause significant changes in predicted noise levels.

Correlation was poor during hover IGE primarily because of acoustic near-field and aerodynamic ground effects. Insufficient data were obtained during this study to define the envelope of aircraft altitude and relative field-point location that result in accurate hover noise predictions, but placement of the rotor two or more diameters above the ground should insure satisfactory correlation. Neither the original analysis (Reference 1) nor the modified analysis should be used to predict rotational noise levels generated during operation IGE. In addition, it is advisable to avoid calculating noise at points near the plane of rotor because of the theoretical minimum being much more severe than the experimentally observed minimum.

EFFECT OF CHORDWISE PRESSURE DISTRIBUTION ON CALCULATED NOISE

Results of the present study indicate that noise levels calculated with the rectangular chordwise distribution can be significantly below those calculated with the measured chordwise distribution even for the second harmonic (Figures 5 and 6). Since the same number of airload harmonics are used in each case, the controlling source of the different noise levels is the shape of the chordwise pressure distribution. Figure 15 presents a differential pressure distribution measured with the NH-3A at 165 knots. The negative pressure region on the trailing surface of the blade is typical at this spanwise location. For comparison, Figure 16 presents a distribution that typifies the CH-34 data used in Reference 1. Intuitively, a rectangular distribution approximates the distribution of Figure 16 much better than it approximates the distribution of Figure 15.

Figure 17 compares measured and calculated noise levels 400 feet in front of the aircraft for the 165-knot, low-wing-lift flight condition. Calculated levels are based on 8 input loading harmonics. The spectrum predicted with the measured chordwise distribution correlates nicely with measured data, while the other predicted spectrum falls off too rapidly to be useful beyond the second harmonic. In this case, the shape of the pressure distribution has compensated significantly for the missing high-frequency airload information. From a practical viewpoint, realistic noise levels can be predicted from relatively few loading harmonics if the

shape of the chordwise pressure distribution is known.

The authors believe that, in general, it is advisable to use the actual chordwise pressure distribution for rotational noise calculations. Otherwise, significant contributions to the noise field from reversed flow and other aerodynamic phenomena will be missing from the computed levels. However, in many cases, chordwise loading data will not be available. This is especially true during the design stage of new aircraft when trade-offs between performance and acoustic annoyance and detectability must be made. Some form of chordwise loading model must be used, but there is not necessarily one model that is always superior to the others.

A rectangular distribution was used in Reference 1 because it approximated the pressures on the CH-34 blades fairly well. Watkins and Durling treated more complex geometric shapes in Reference 3, while Lowson and Ollerhead favored the Dirac delta function as a mathematical representation of the chordwise pressure distribution in Reference 9. The use of a mathematical model for the chordwise distribution of pressure simplifies analytical expressions, making the equations less general. The resultant simplification of computer programs and saving of computing time are attractive reasons for abandoning the measured chordwise distribution in favor of a mathematical model, assuming that this will result in good acoustic correlation. The critical test for any distribution model is the correlation obtained for the higher harmonics of noise.

A rectangular model is acceptable when reversed flow and other unsteady phenomena do not contribute significantly to the radiated noise. The approach of Watkins and Durling can be used to represent reversed flow effects, but practical problems are likely to be associated with assigning a realistic distribution to different areas of the rotor disc. Both the Dirac delta and the rectangle have the shortcoming of assigning one distribution to all regions of the rotor disc. In summary, it is desirable to use the actual chordwise pressure distribution when calculating rotational noise levels from unsteady airload data, especially if relatively few loading harmonics are available. In cases necessitating use of a chordwise model, the inherent limitations of any model must be considered.

EFFECT OF HIGH-FREQUENCY AIRLOADS ON CALCULATED NOISE

The 165-knot, low-wing-lift case was studied to determine the effect of high-frequency airload harmonics on predicted noise. Calculated noise levels were based on 8, 16, 20, and 30 input loading harmonics (plus steady loading) obtained from an average of 4 cycles of pressure around the azimuth. The results are presented in Figures 18 and 19. Figure 18 shows the levels predicted by the original analysis with a rectangular chordwise distribution of differential pressure. The first noise harmonic is not sensitive to changes in the number of loading harmonics. Sensitivity increases rapidly with harmonic order, as indicated by the noise levels predicted from 8 loading harmonics. Figure 19 presents the corresponding results obtained using the modified analysis with the actual chordwise distribution of differential pressure. The trends are similar, with no sensitivity for the first noise harmonic and increasing sensitivity for the

higher noise harmonics. These results corroborate the conclusions in Reference 1 regarding the importance of high-frequency airloads for the prediction of the higher harmonics of rotational noise.

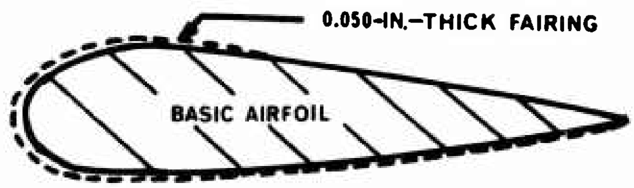
Note that the use of more loading harmonics does not necessarily result in higher predicted noise levels. Adding loading harmonics causes the computed levels to decrease for some field points and to increase for others because of phasing. Consequently, Figures 18 and 19 do not make clear just how many harmonics are required for acceptable results. The simplest guideline is to use at least mB harmonics of load, where m is the noise harmonic order and B is the number of blades in the rotor system.

The need for high-frequency loading information in rotational noise prediction poses a difficult problem. In aircraft design studies, high-frequency airloads generally are as much of an unknown as the shape of the chordwise pressure distribution. In fact, there is relatively little interest in high-frequency aerodynamic blade loadings among performance and structural analysts. This forces acoustic analysts to develop their own techniques for obtaining the aerodynamic data required for rotor noise prediction. The analytical tools currently being developed hold great promise for improving correlation of low-frequency airloads and rotor blade dynamic response. Research work in rotary wing acoustics will have to include acquisition of extensive flight data with which to establish empirical loading laws for the higher harmonics. These laws can then be used to extend the analytical loading data through the frequency range of interest acoustically.

EFFECT OF INSTRUMENTATION FAIRINGS ON AIRLOADS AND PREDICTED NOISE

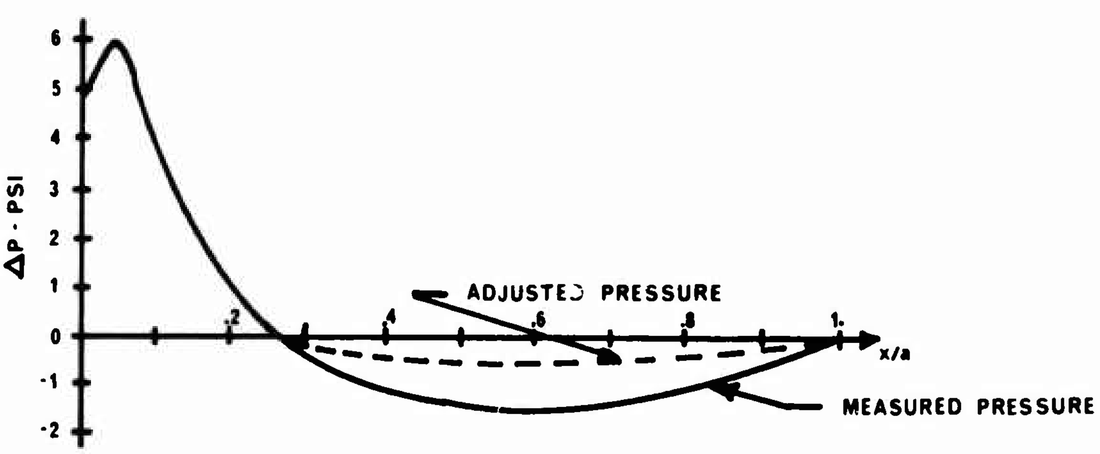
Chordwise pressure distributions similar to Figure 15 raise questions about the aerodynamic characteristics of the instrumented main rotor blade. Negative differential pressures are common on helicopter rotor blades with symmetrical airfoil sections because of the unsteady flow environment, but the magnitudes of the negative pressures measured on the aft portion of the S-61F instrumented blade are larger than expected. Because of these negative pressures, the rotor thrust calculated by integrating measured steady airloads over the rotor disc is as much as 30 percent lower than expected.

An extensive review of the instrumentation used to measure the pressures on the blade confirmed that neither instrumentation inaccuracy nor calibration errors are responsible for the large negative pressures. Rather, the geometry of the instrumented airfoil in the vicinity of the pressure transducers has an effective negative aerodynamic camber due to the instrumentation fairing that can lead to increased negative lift on the aft portion of the blade. This fairing around the pressure transducers is sketched below for a typical instrumented blade section. Termination of the fairing at about mid-chord on the upper surface of the blade causes an effective negative camber of 0.25 percent chord. This fairing design was dictated by requirements for low weight coupled with good strength, reliability/maintainability, and aerodynamic characteristics.



SKETCH OF INSTRUMENTED AIRFOIL SECTION

The effect of this effective negative camber on predicted noise was found to be less than 1.5 dB for the first four harmonics of rotational noise. To determine this, the steady component of differential pressure acting on the aft portion of the blade was adjusted to be more typical of a symmetric rotary-wing airfoil. These adjusted pressures were chosen to provide a smooth transition from the measured value at 30 percent chord to zero at the trailing edge. The sketch below illustrates the difference between measured and adjusted steady pressures. Note that changing the pressure distribution does not preclude the occurrence of negative differential pressures. Noise levels were calculated from the total differential pressure obtained from the adjusted steady pressures and the measured oscillatory pressures. The levels so calculated differed from levels calculated from the actual measured pressures by less than 1.5 dB for the fundamental harmonic. Because of the increased thrust, the adjusted levels are the louder of the two. This difference decreases with increasing noise harmonic order because the oscillatory pressures acting on the rotor blades control the levels of the higher-order noise harmonics while the steady pressures control the level of the fundamental.



SKETCH OF MEASURED AND ADJUSTED PRESSURE DISTRIBUTIONS

It should be noted that the negative pressure on the aft portion of the instrumented blade sections will become acoustically significant only as the wavelength of the noise approaches the dimension of a blade chord. This corresponds approximately to the 40th noise harmonic for the S-61F rotor system. The value of an open-form acoustic solution is questionable at such high noise harmonic orders, making the problem somewhat academic.

GENERAL COMMENTS ON AERODYNAMIC DATA

Although the preceding investigation confirms the validity of the acoustic results presented in this report, some general comments on the validity of the aerodynamic pressure data are in order. The negative steady differential pressures measured on the aft portion of the instrumented blade are valid, but they are only known to be characteristic of the 10 percent of the blade covered by the instrumentation fairings. The rest of the blade apparently performed as a normal uninstrumented blade since no blade track or fuselage vibration problems were encountered. Oscillatory pressures are considered valid because of the results of the present study and those of the study that developed the airborne data acquisition system for a correlation study of airloads, blade root shears, and fuselage response (Reference 4).

Any future studies that use the aerodynamic data presented in Tables II through VI should consider the consequences of assuming that the steady differential pressures measured on the rear of the blade are typical for an entire rotor system comprised of blades having symmetrical airfoil cross-sections. Oscillatory pressures, on the other hand, may be used with confidence.

CONCLUSIONS

1. Both high-frequency airloads and the chordwise distribution of loading are important for rotational noise prediction.

2. The acoustic effect of phasing of the higher loading harmonics makes it difficult to define how many loading harmonics are required in practice. The suggested guideline is to use at least mB loading harmonics to obtain m noise harmonics.

3. The shape of the chordwise distribution of differential pressure can partially compensate for a lack of high-frequency airload data.

4. Differences from cycle to cycle of blade pressure data for any given flight condition can cause drastic variations in predicted noise harmonic levels. Consequently, the cycles of blade pressure data used for correlation studies must be selected carefully to correspond with the noise that resulted from these pressure oscillations.

5. It is advisable not to attempt correlation for field points lying near the plane of the rotor because of the extreme sensitivity of directional characteristics in this region.

6. This study did not reveal degradation of correlation attributable to forward motion effects.

7. The measured steady component of differential pressure on the aft portion of the blade is not characteristic of a symmetrical airfoil and should be used with knowledge of the aerodynamic effects of the fairings around the pressure transducers.

RECOMMENDATIONS

The present study did not encounter any impulsive rotor noise, or "blade slap" as it commonly is called. It is recommended that a helicopter that produces impulsive noise be instrumented for a prediction and correlation study. Such a program will define how well the present analysis predicts impulsive noise, and it also will provide the data required to define the aerodynamic mechanisms that produce impulsive noise.

It is recommended that rotor orientation and source translational motion terms be added to the present noise analysis in order to corroborate the interpretation of correlation presented in this report. While the correlation obtained during this study showed no adverse effects from excluding orientation and motion, these factors should be included for noise prediction at high forward speed and at very large distances in front of the helicopter.

Acoustic evaluation of advanced rotor and propeller systems requires accurate aerodynamic loading data for use with noise prediction analyses. Since no methods presently exist for predicting the amplitude and frequency distribution of airloads with accuracy sufficient for good acoustic predictions, it is recommended that extensive analytical and experimental work be done to define these loads. Specifically, better information is required about the trajectories of rotor wakes in forward flight, about the chordwise distribution of airload as a function of radius and azimuth, and about the velocity, diameter, and decay characteristics of the trailing tip vortices.

Another potential way to evaluate the acoustic characteristics of advanced rotors (or propellers) is to scale measured model rotor noise to full-scale conditions. No comprehensive information is currently available in this area, and it is recommended that techniques for scaling model rotor noise be developed.

The problems that the present study encountered in correlating hover noise illustrate the need for defining the acoustic differences between hover IGE and OGE. A detailed noise survey is recommended to quantify the differences in intensity and directionality between these two regimes.

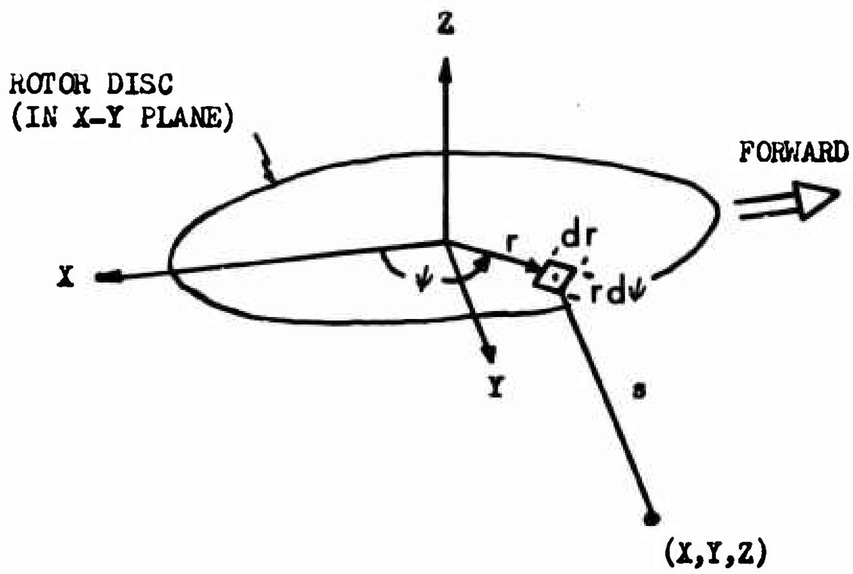


Figure 3. Coordinate System Convention.

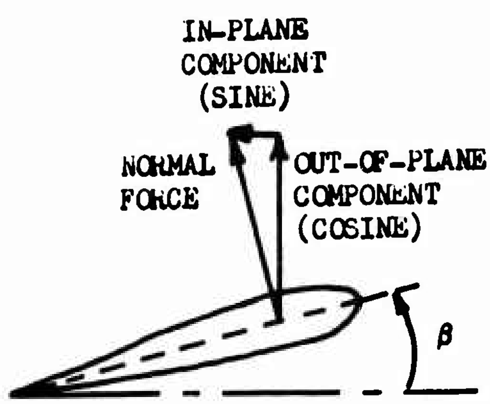
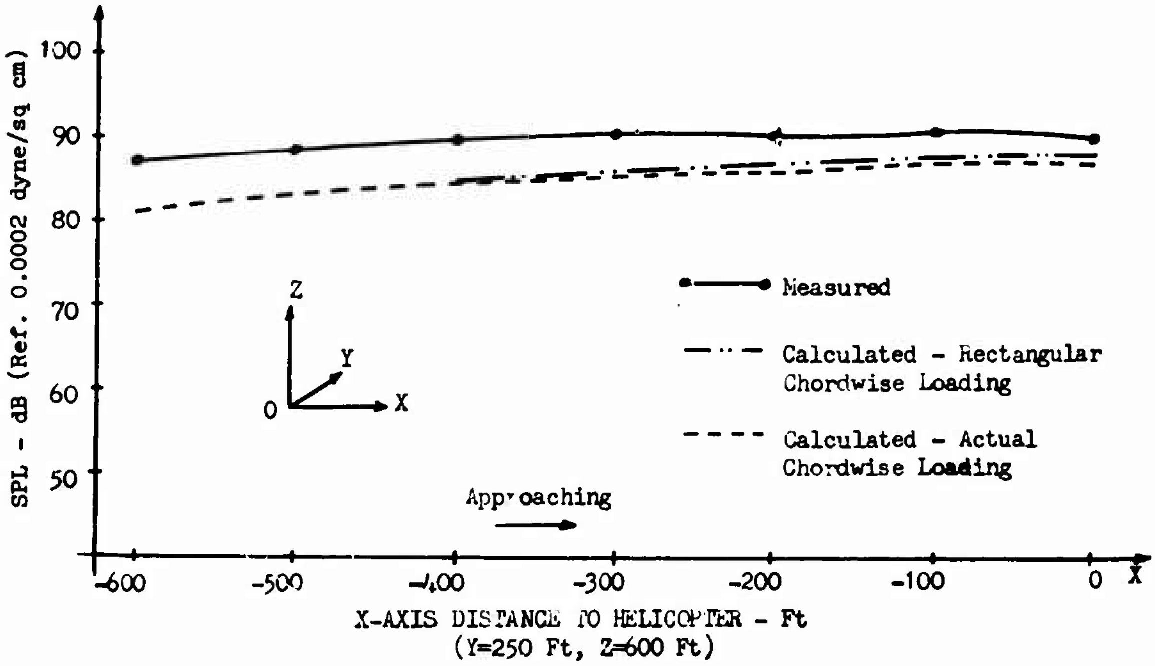
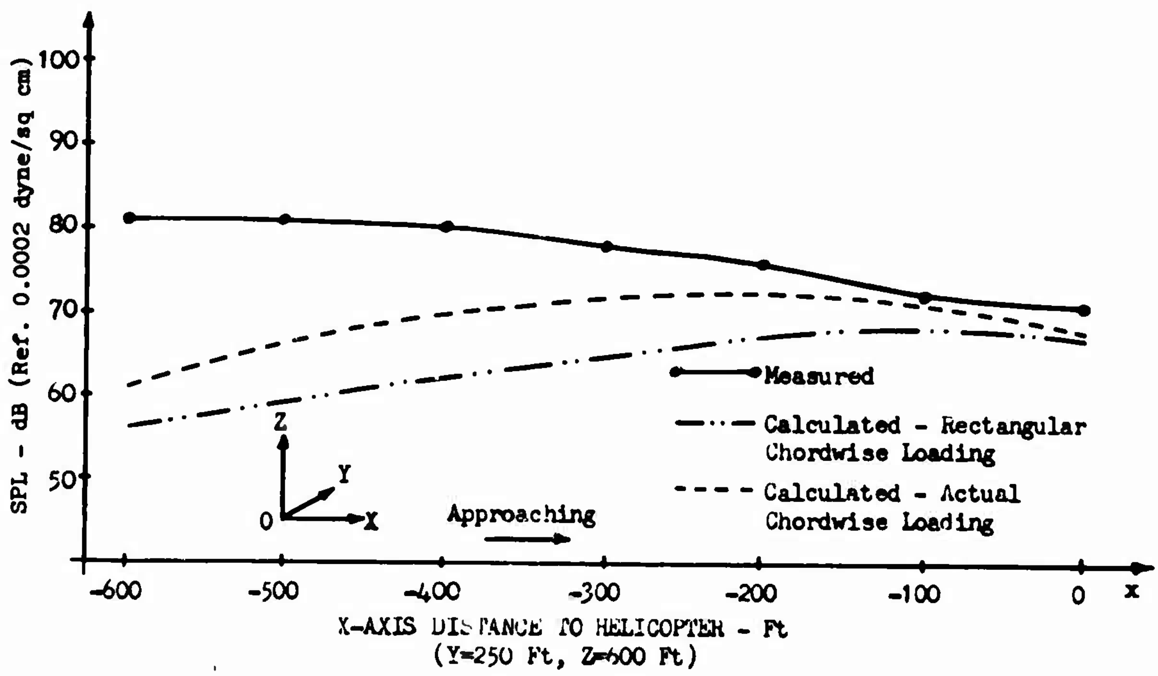


Figure 4. Blade Pitch Angle and In-Plane and Out-of-Plane Components of Load.

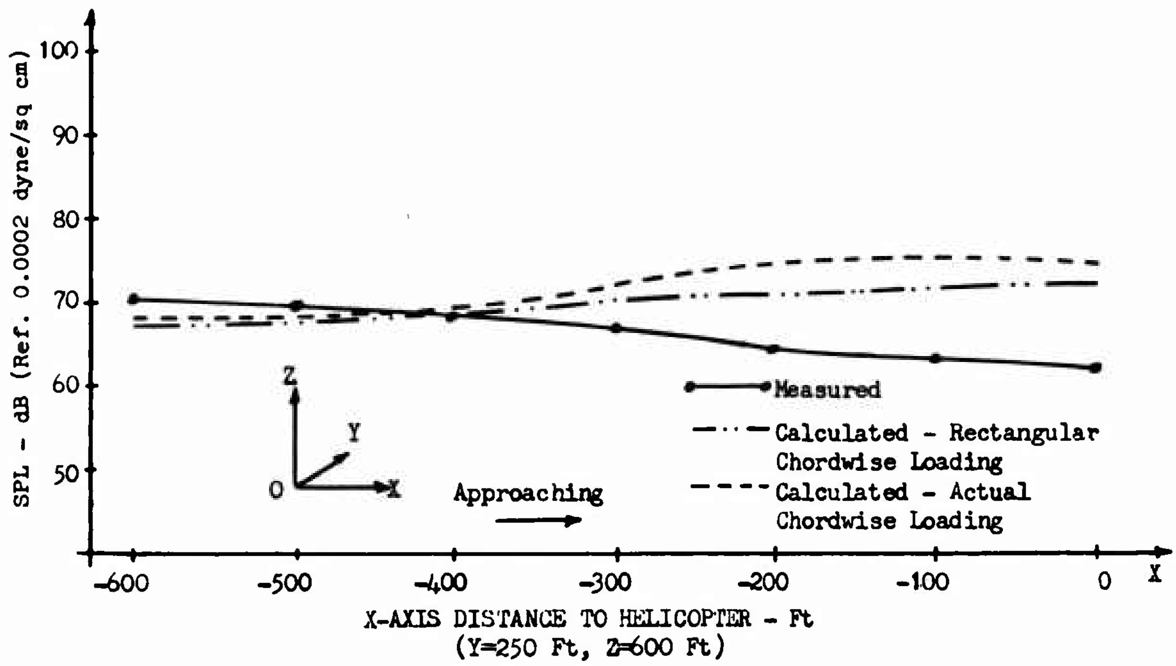


a. First Harmonic.

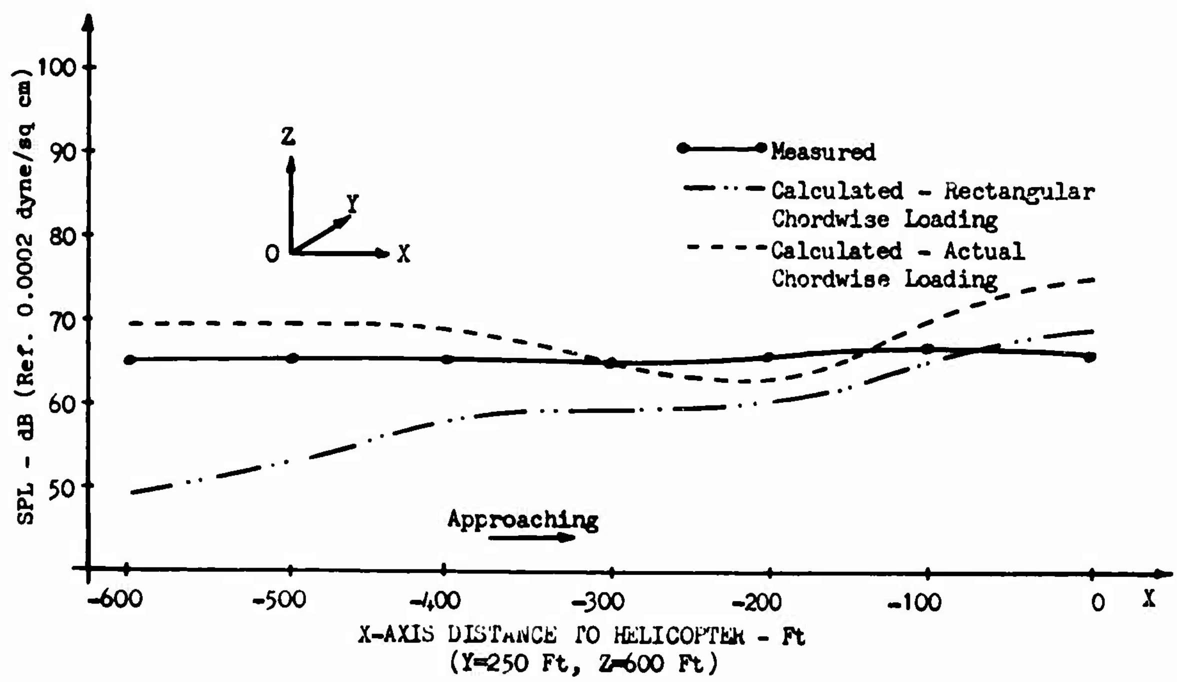


b. Second Harmonic.

Figure 5. SPL vs Distance - 165 Knots, High Wing Lift.

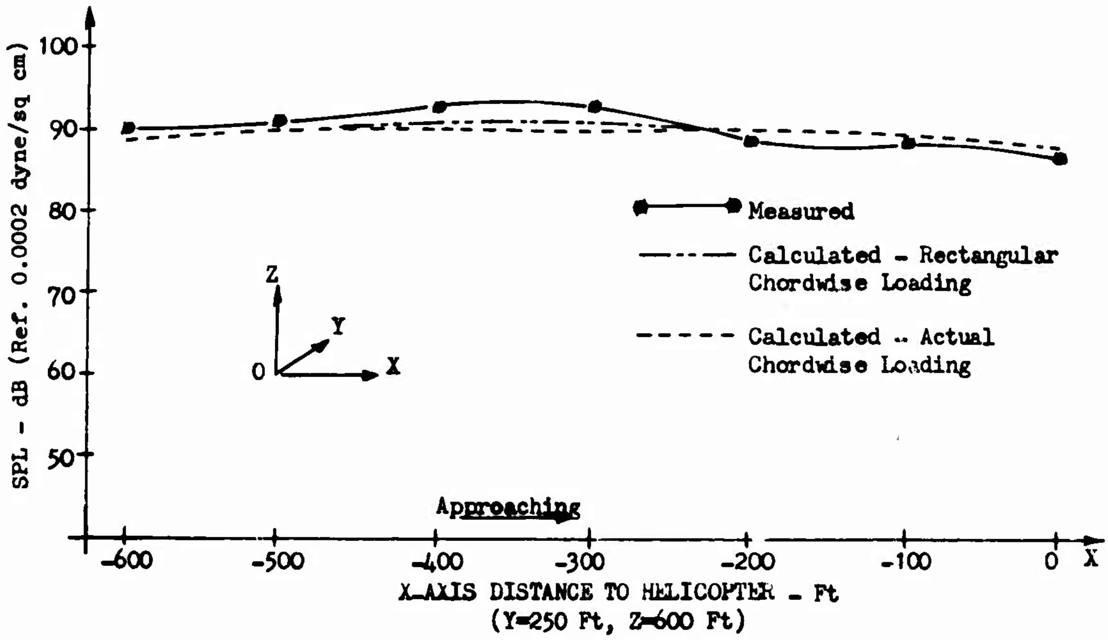


c. Third Harmonic.



d. Fourth Harmonic.

Figure 5. Concluded



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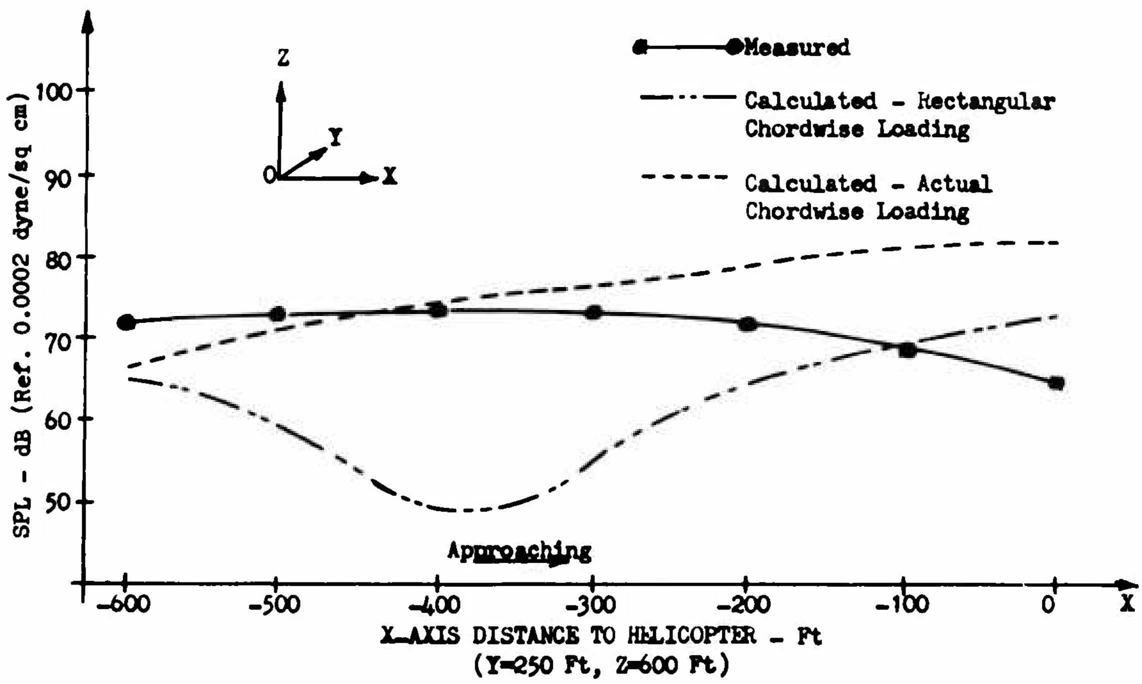
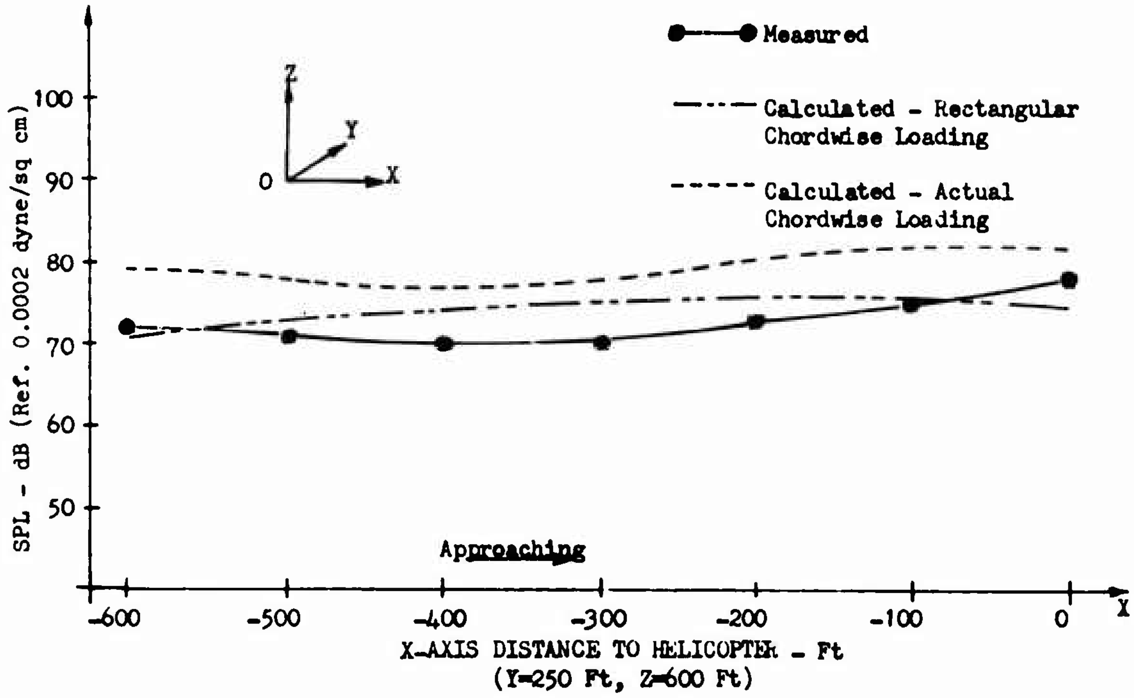
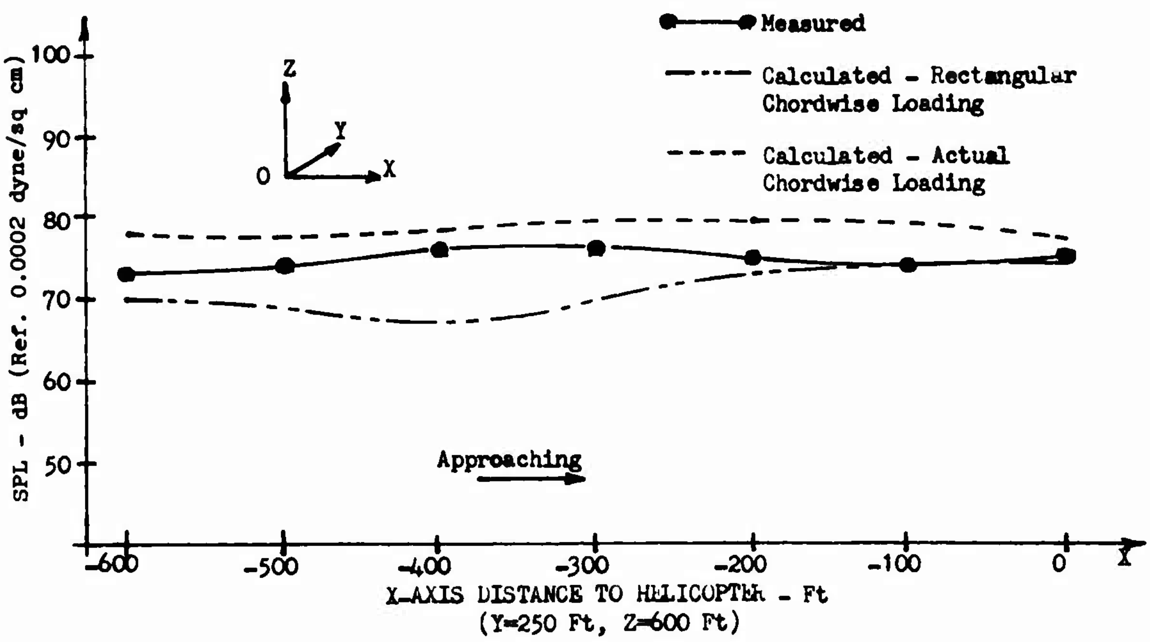


b. Second Harmonic.

Figure 6. SPL vs Distance - 165 Knots, Low Wing Lift.

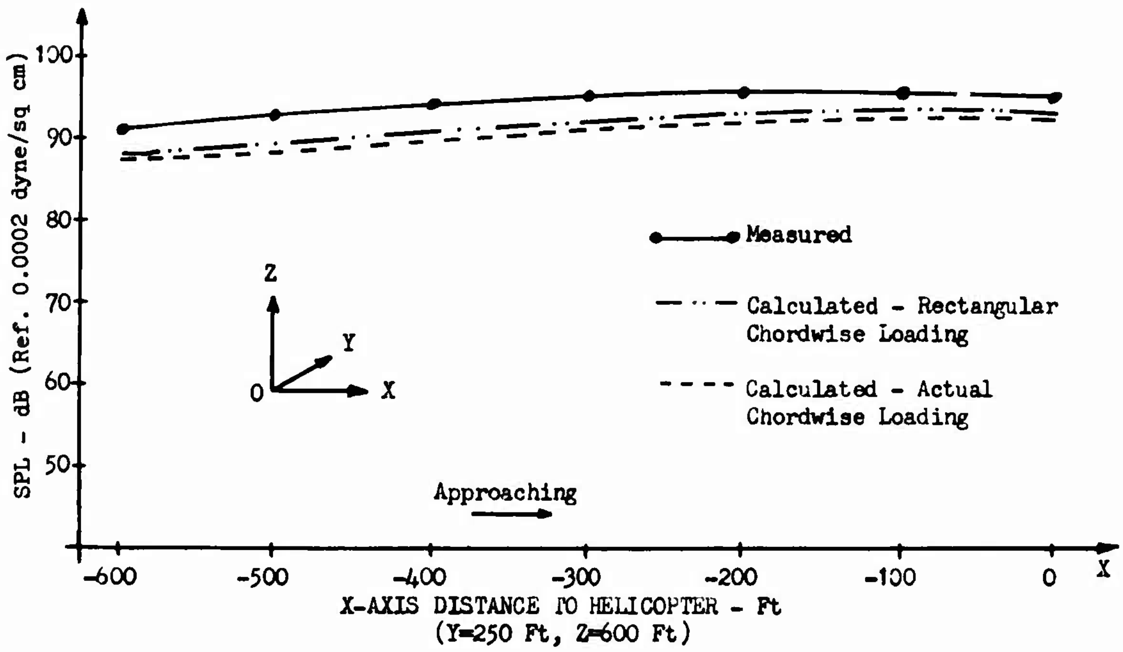


c. Third Harmonic.

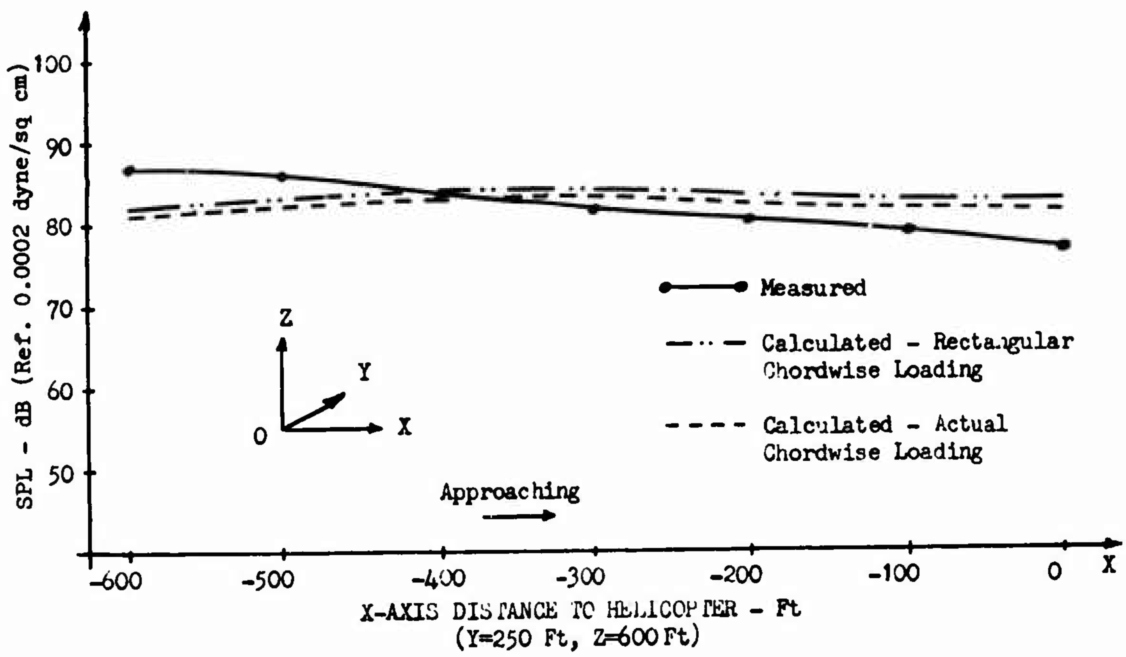


d. Fourth Harmonic.

Figure 6. Concluded.

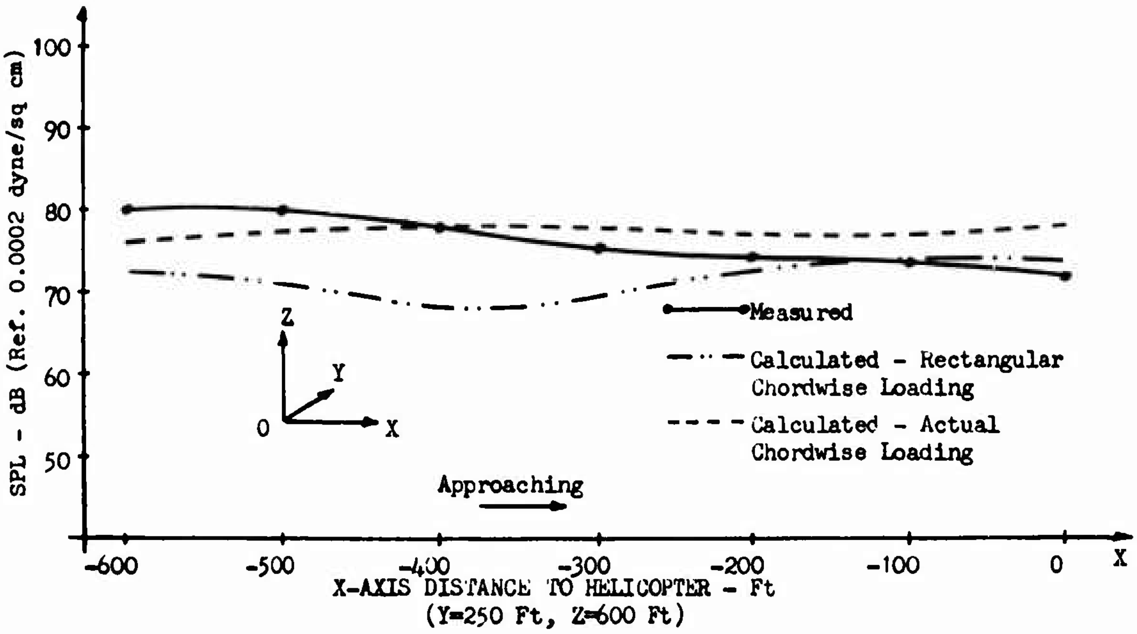


a. First Harmonic.

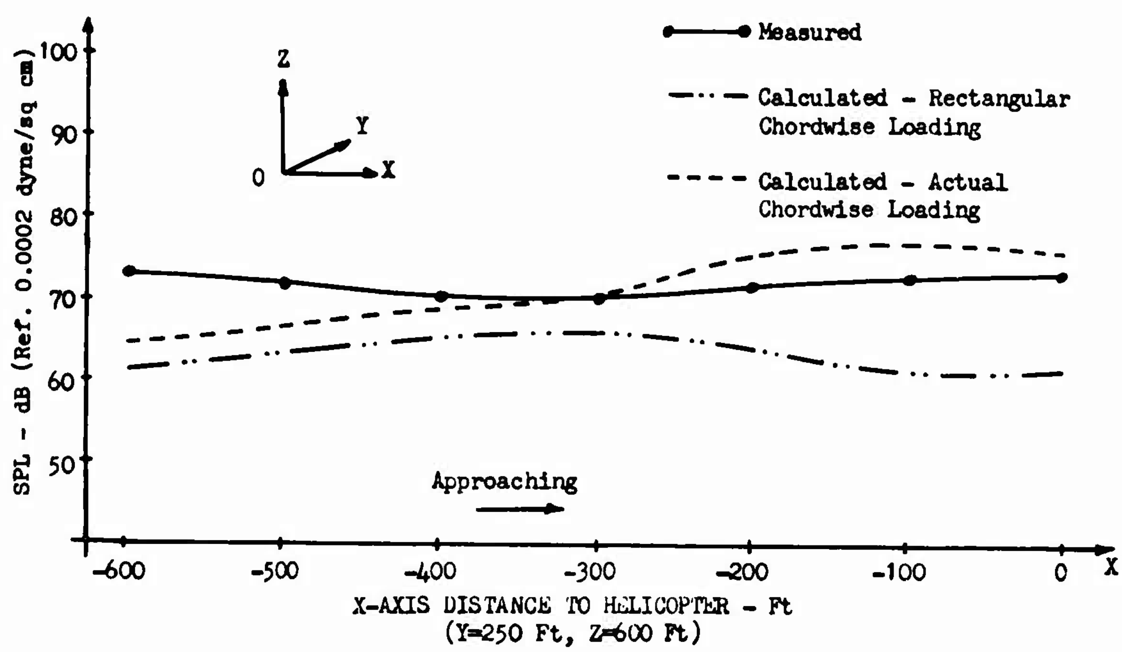


b. Second Harmonic.

Figure 7. SPL vs Distance - 190 Knots, High Wing Lift.

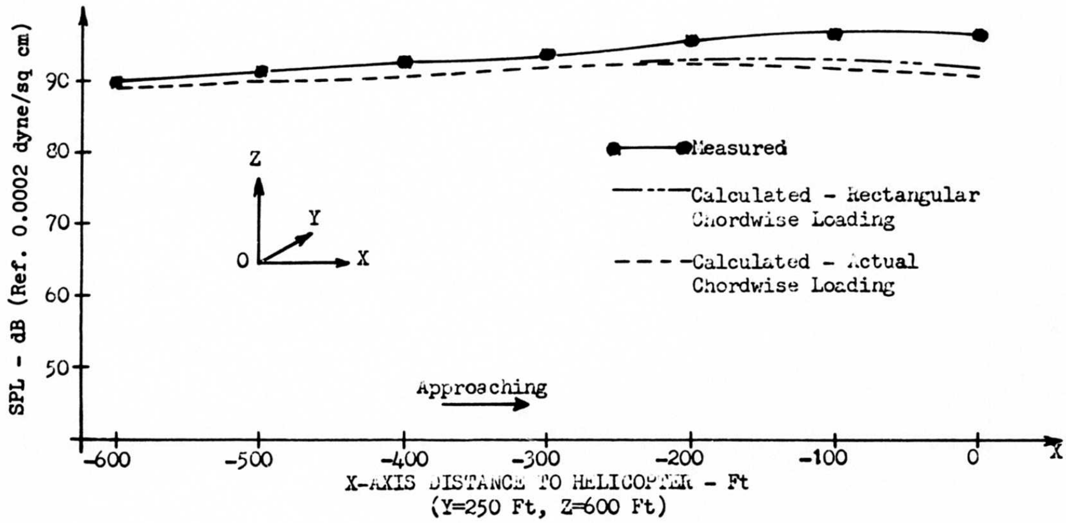


c. Third Harmonic.

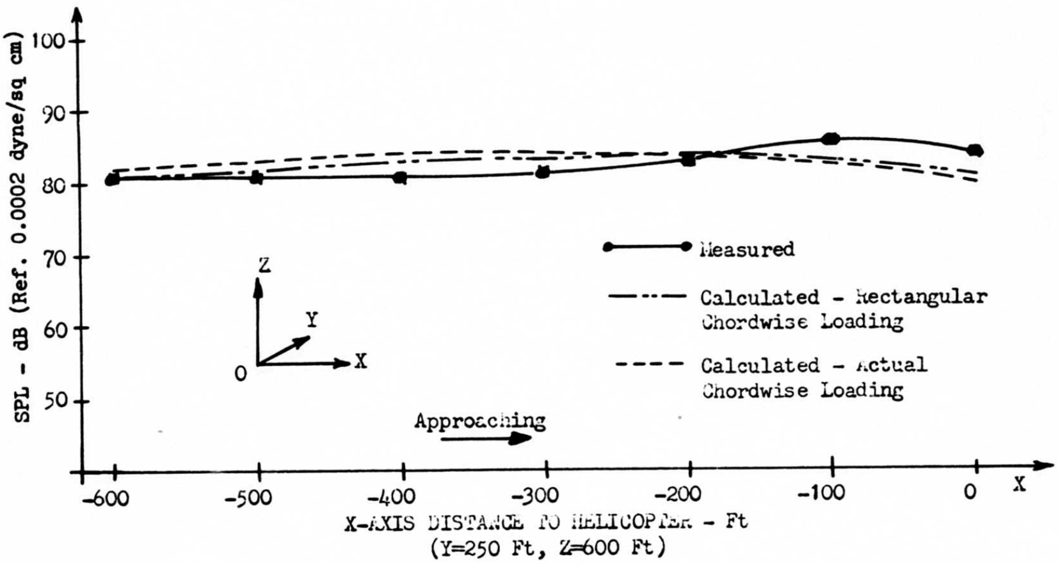


d. Fourth Harmonic.

Figure 7. Concluded.

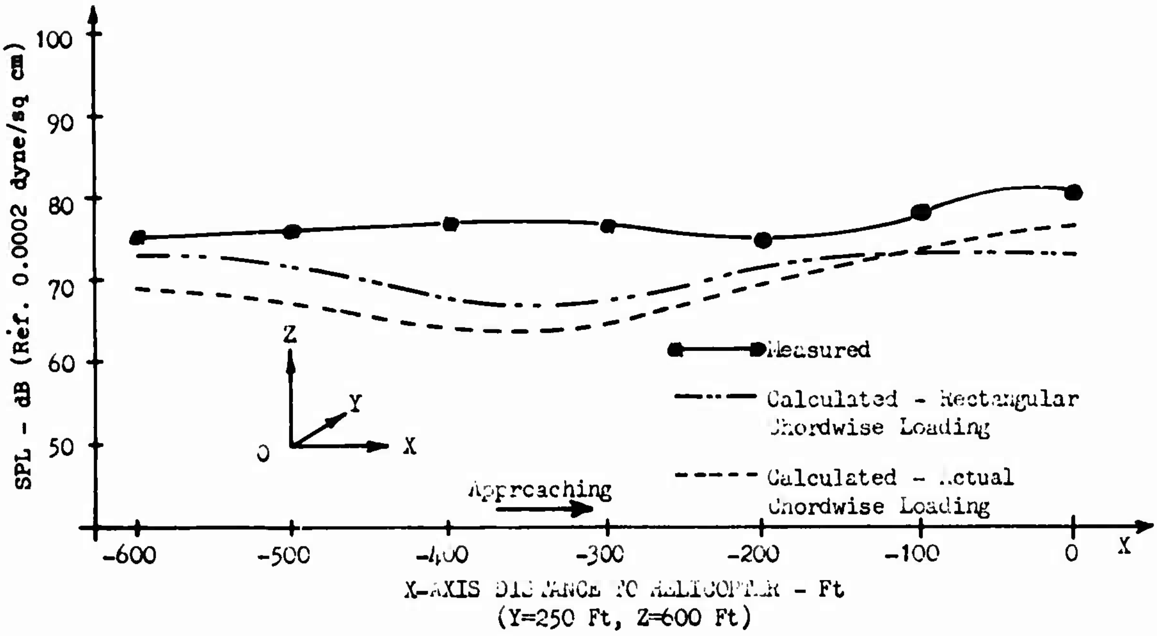


a. First Harmonic.

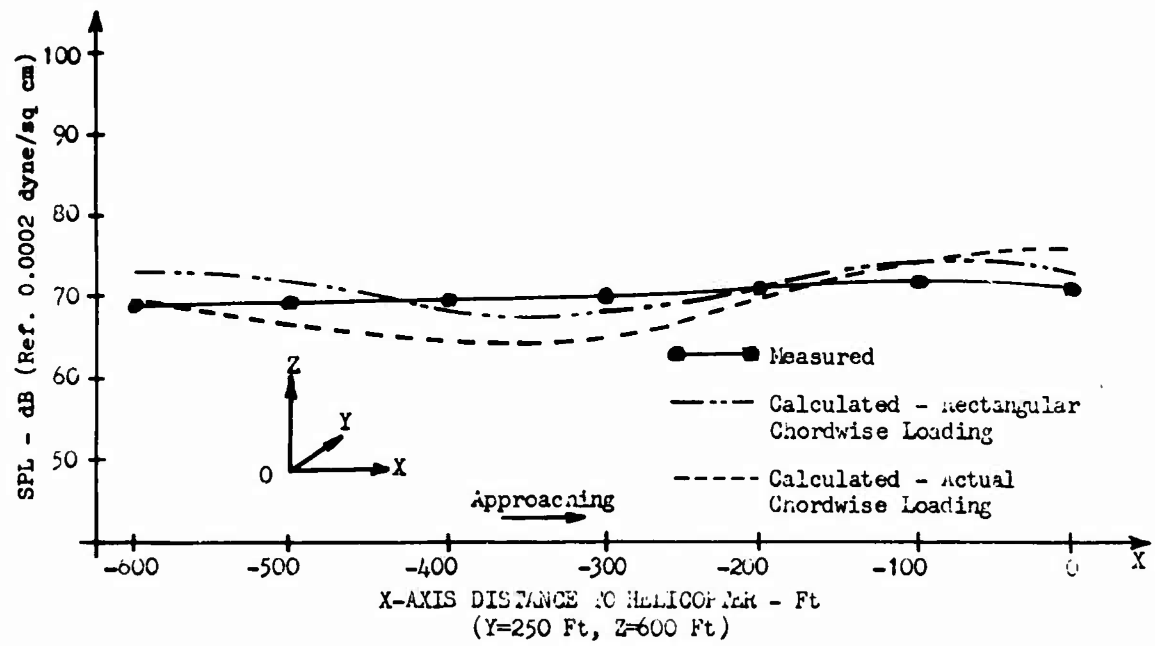


b. Second Harmonic.

Figure 8. SPL vs Distance - 190 Knots, Low Wing Lift.



c. Third Harmonic.



d. Fourth Harmonic.

Figure 8. Concluded.

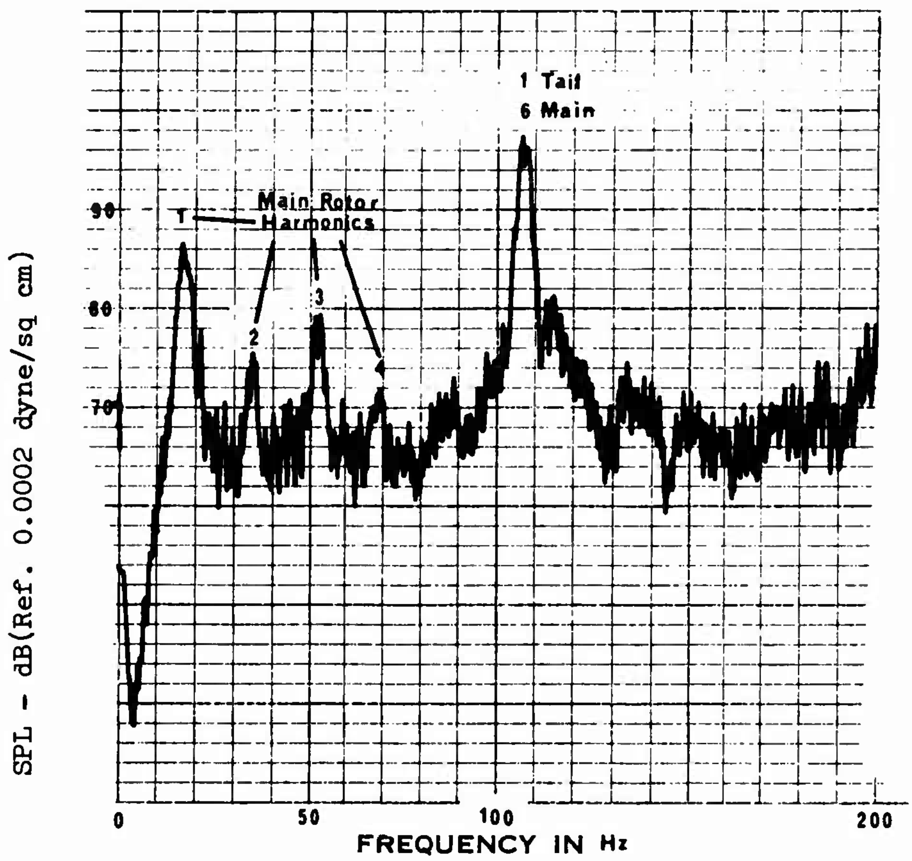
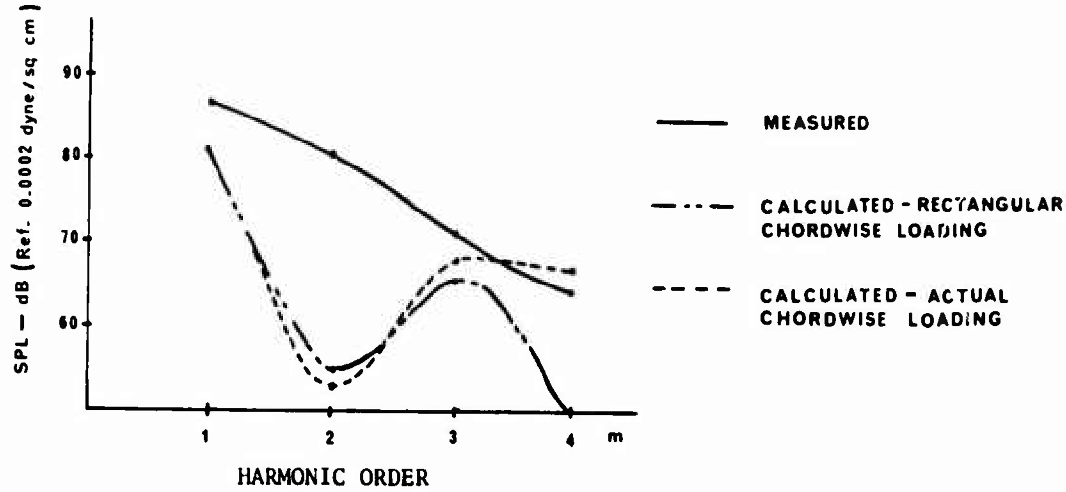
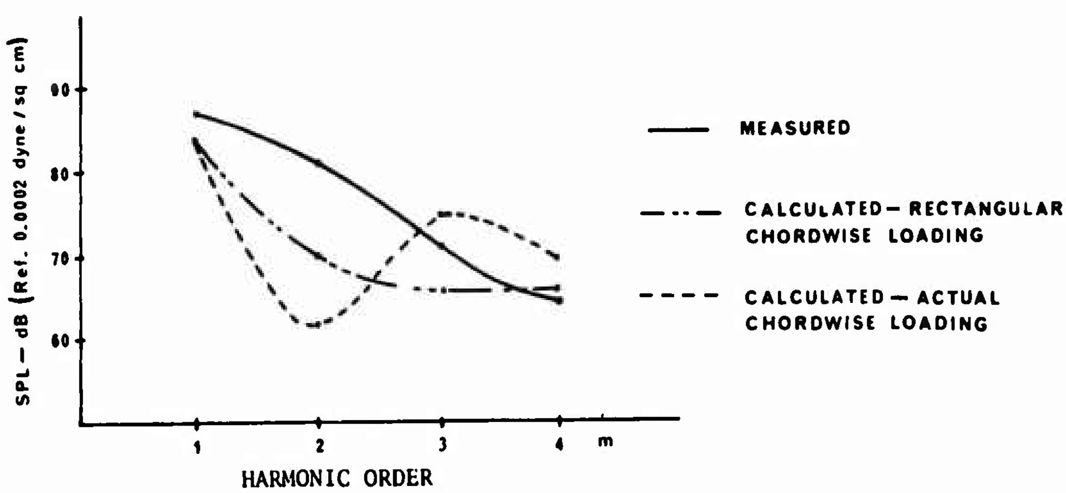


Figure 9. Narrow-Band (8%) Plot of NH-3A Noise, 165 Knots, High Wing Lift.

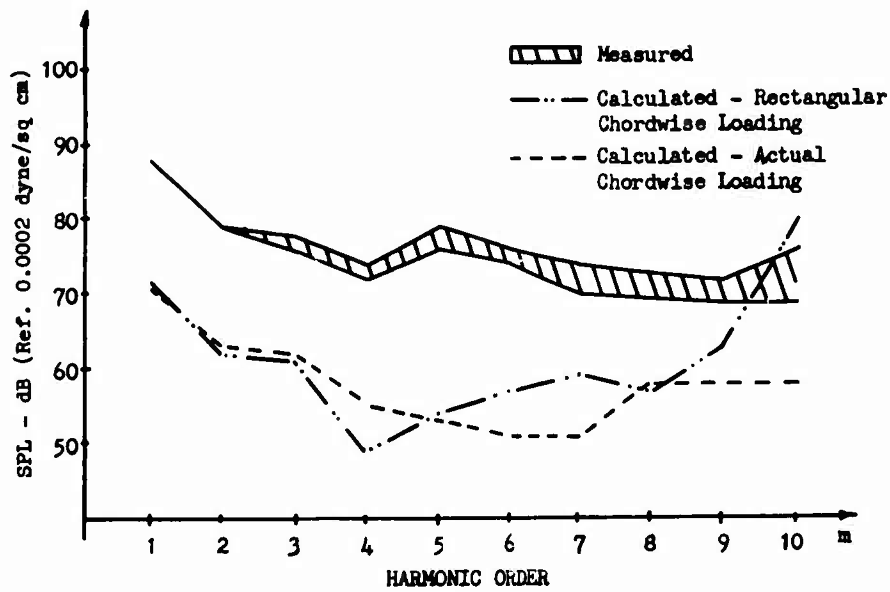


a. First Data Sample, Cycles 5-14.

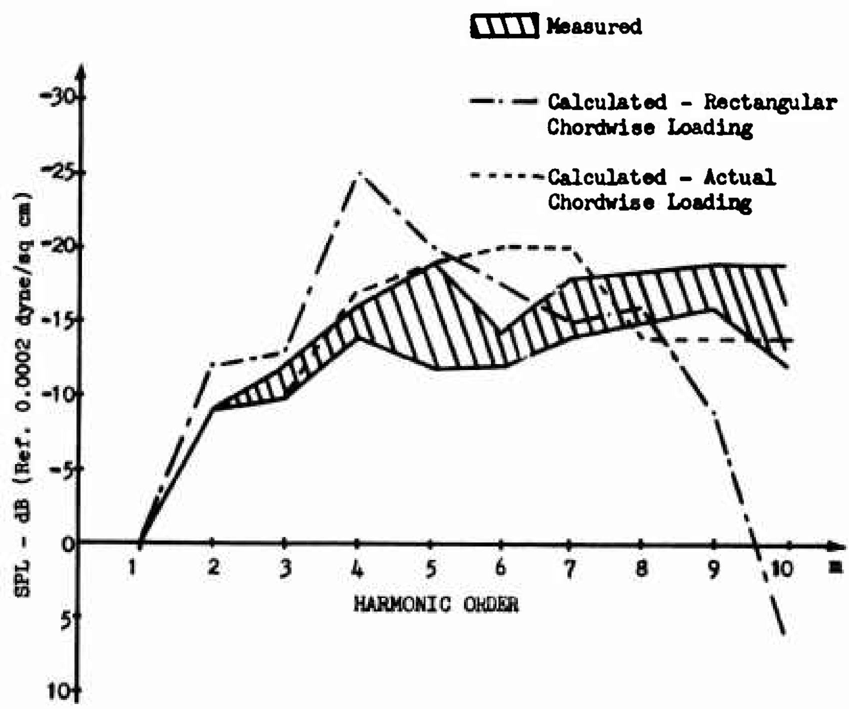


b. Second Data Sample, Cycles 15-18.

Figure 10. Variations in Predicted Spectrum Shape Caused by Input Data.



a. Absolute Levels.



b. Levels Referenced to Fundamental.

Figure 11. Measured vs Calculated NH-3A
Noise Harmonic Spectrum, Hover IGE.

Figure 12. NH-3A Hovering IGE (Note Noise Measurement Station, Lower Right Side).

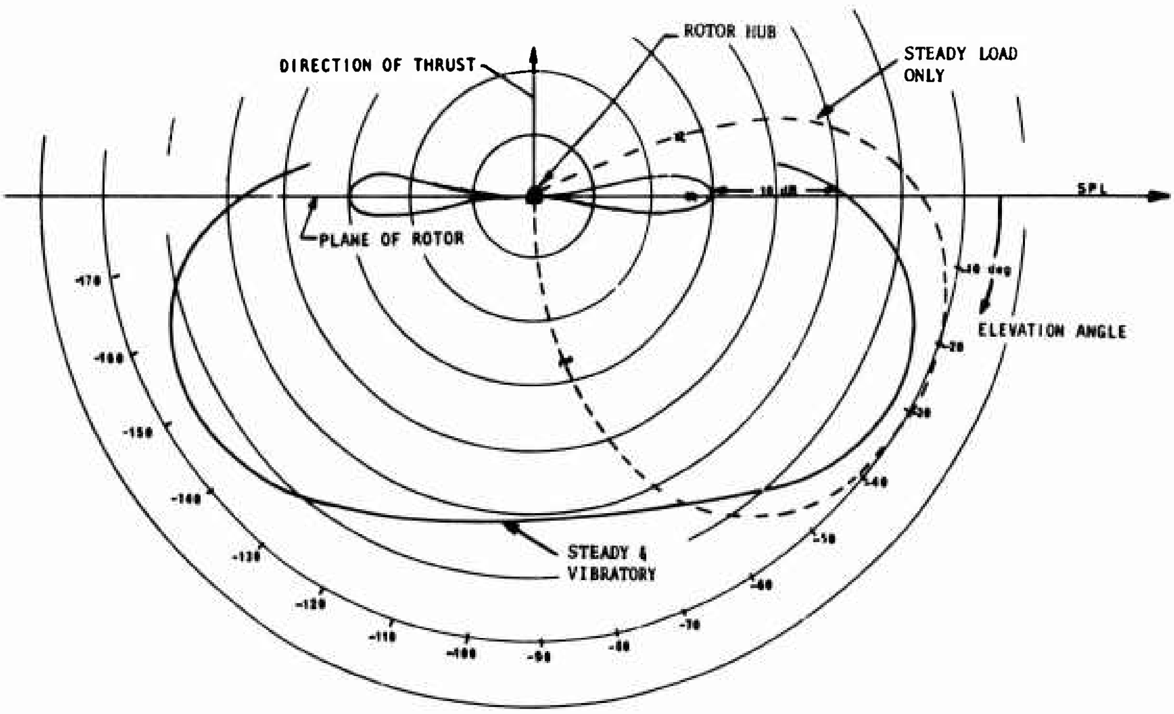
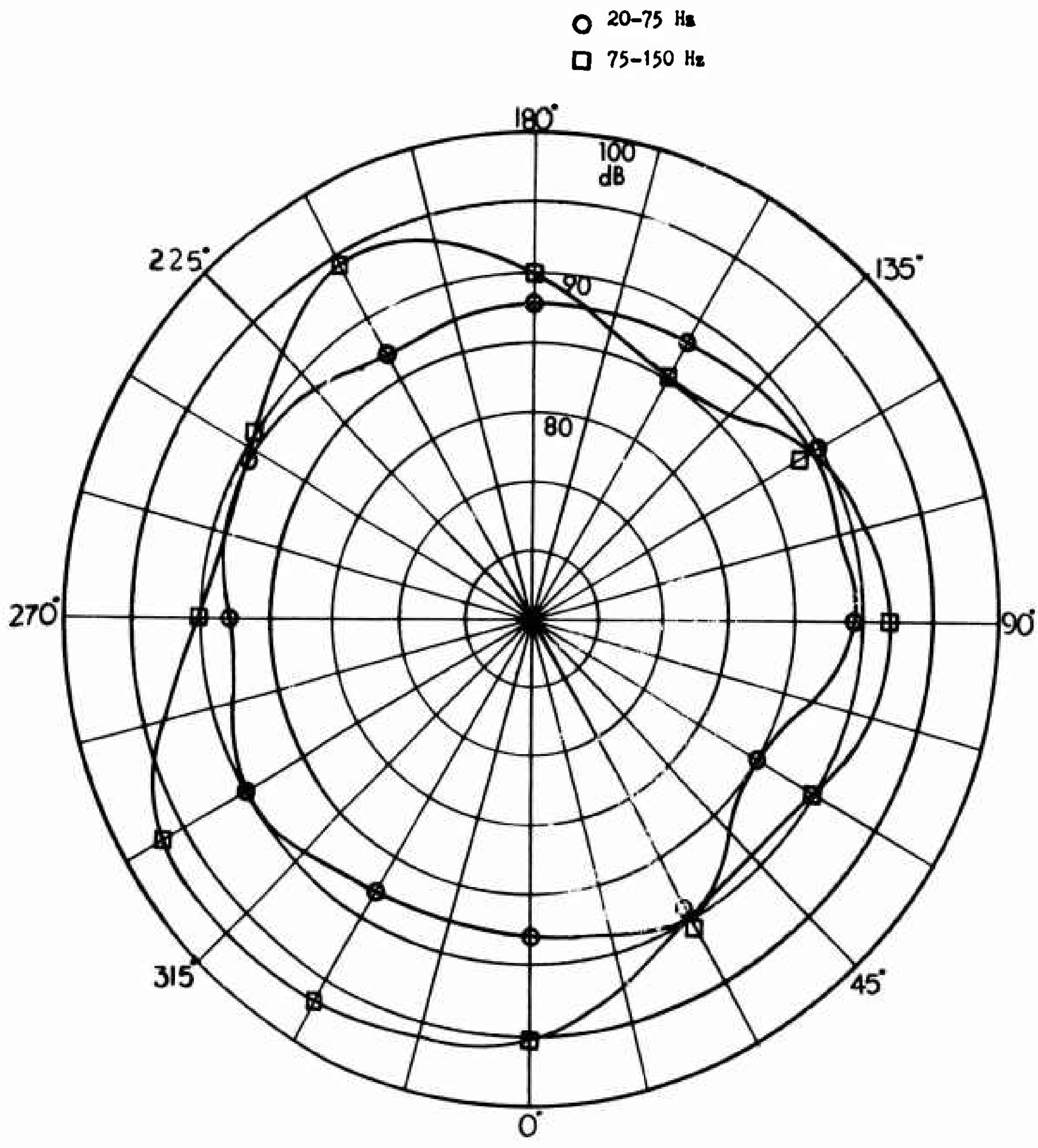
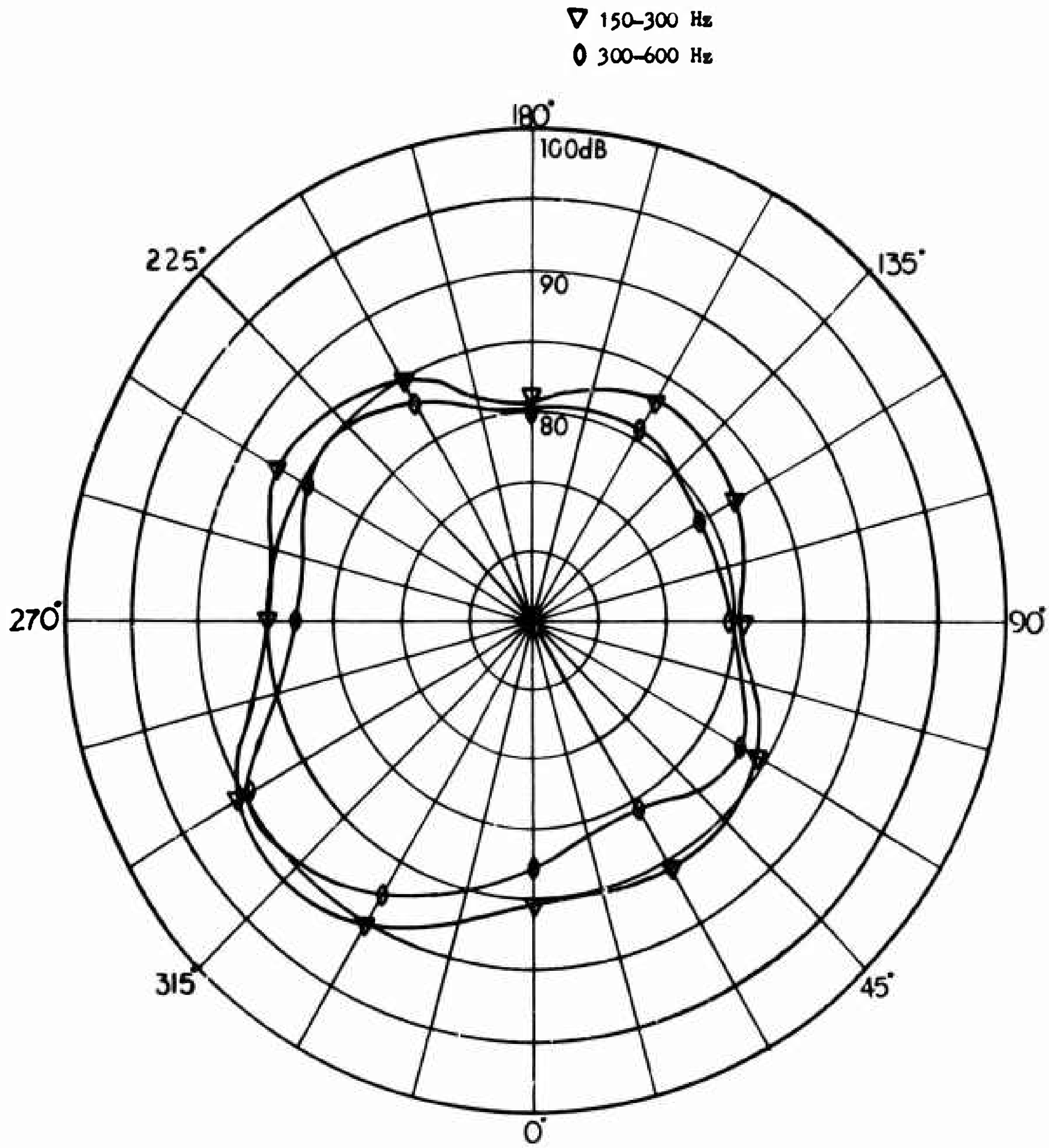


Figure 13. Predicted Directional Patterns.



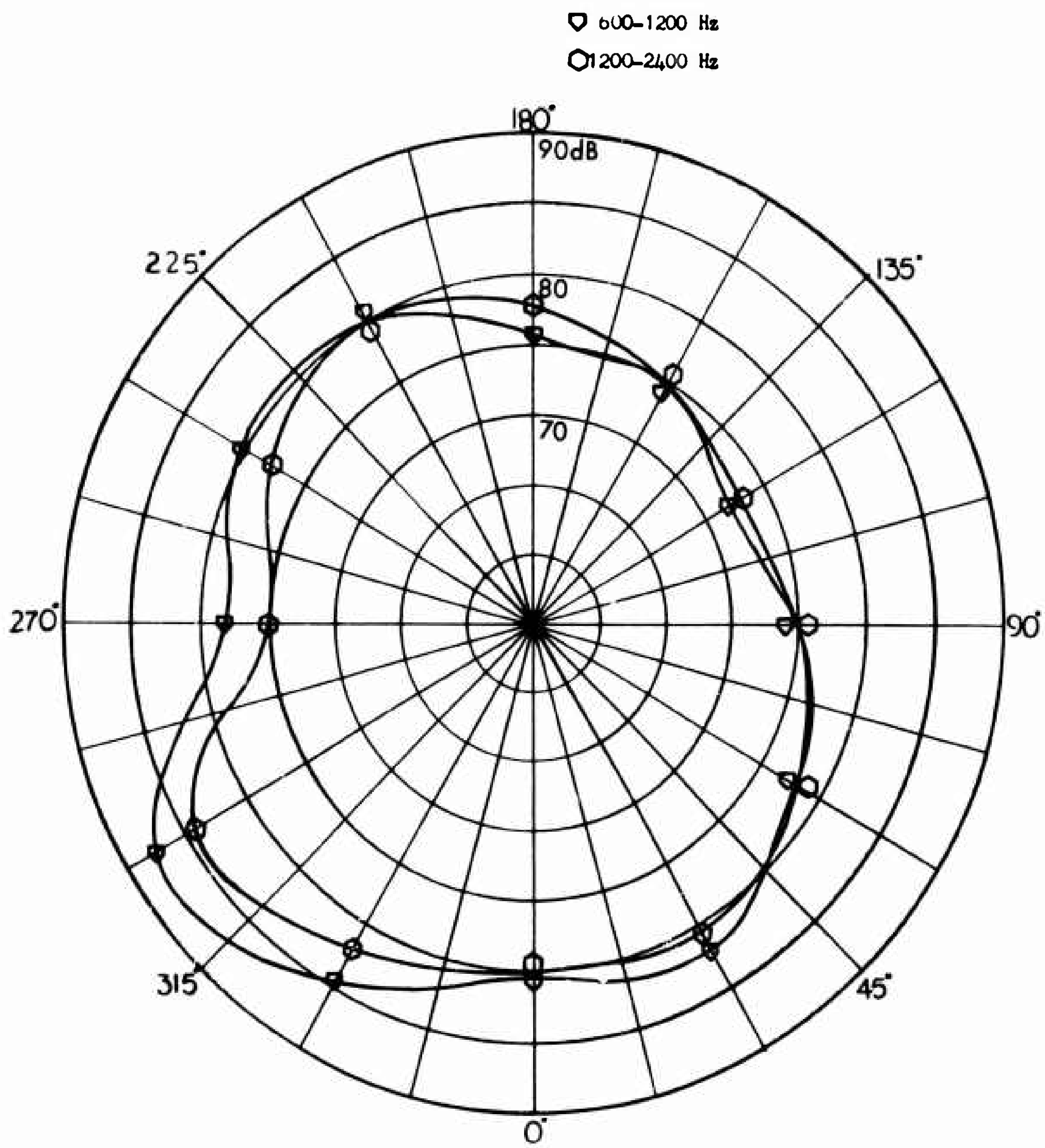
a. First and Second Octaves.

Figure 14. Measured Octave Band Levels - Azimuthal Survey.



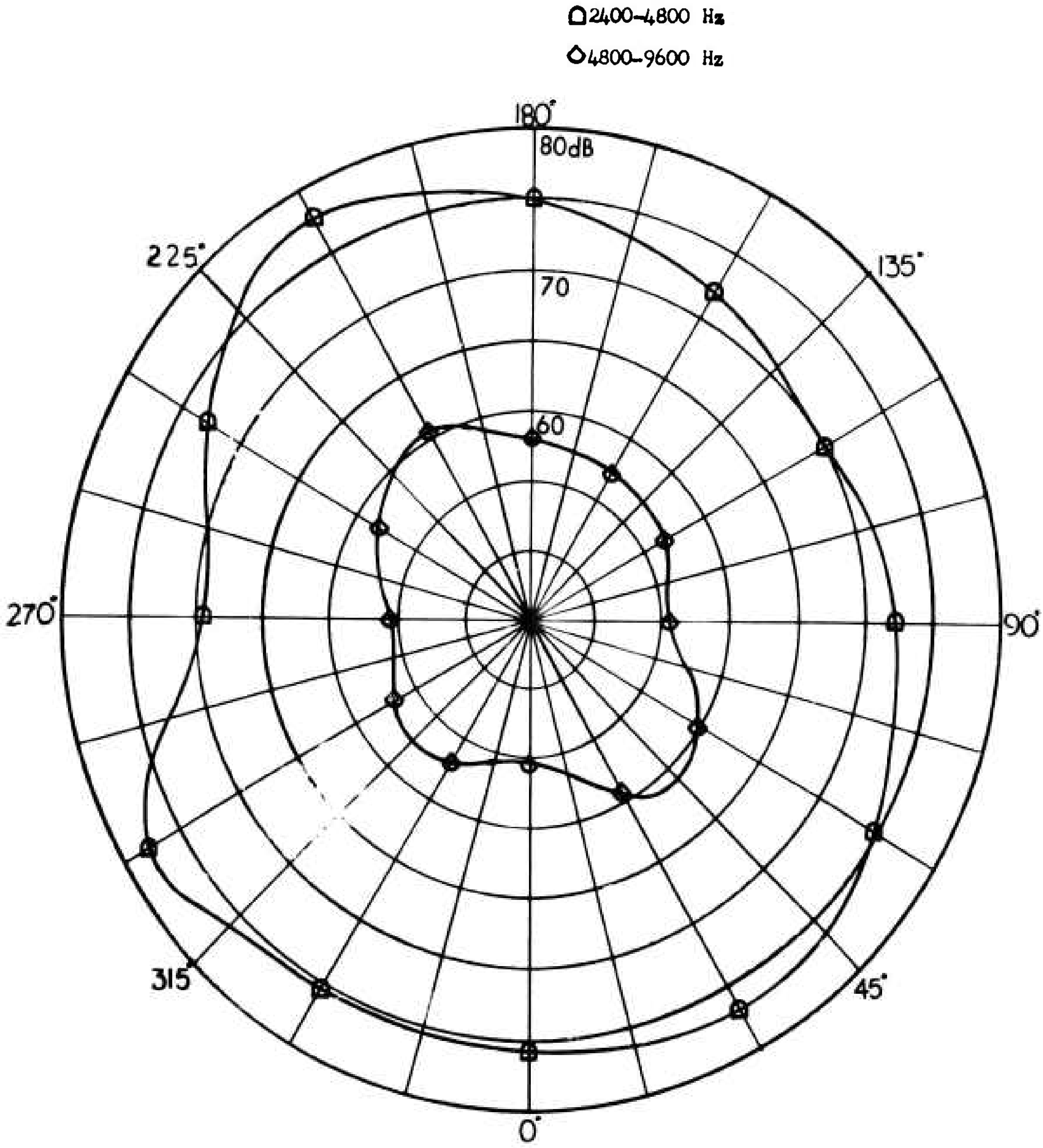
b. Third and Fourth Octaves.

Figure 14. Continued.



c. Fifth and Sixth Octaves.

Figure 14. Continued.



d. Seventh and Eighth Octaves.

Figure 14. Concluded.

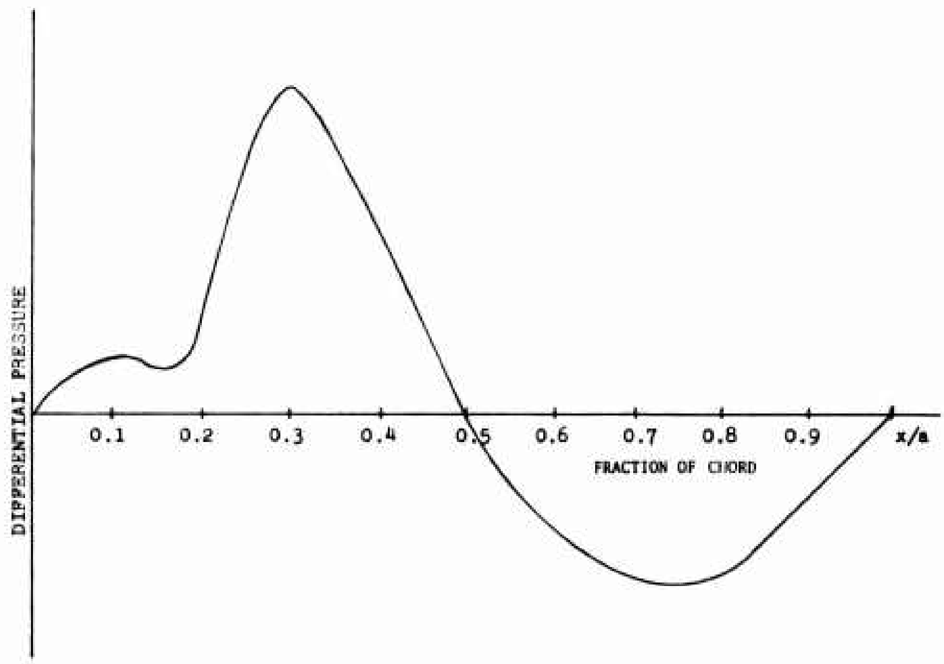


Figure 15. Chordwise Distribution of Differential Pressure, NH-3A, 165 Knots, 85% Span.

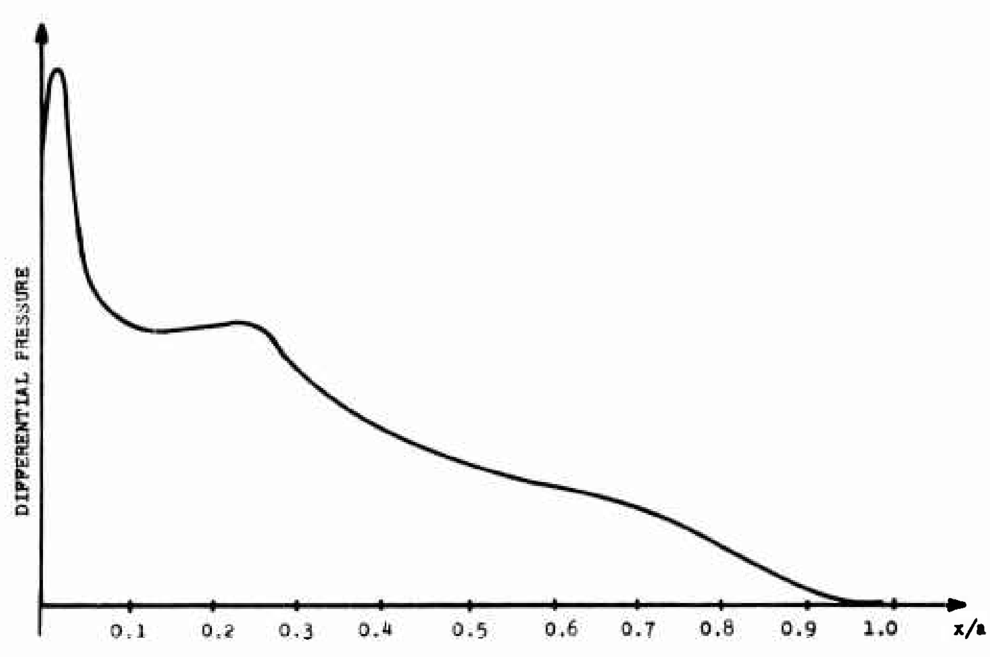


Figure 16. Chordwise Distribution of Differential Pressure, CH-34, 31 Knots, 90% Span.

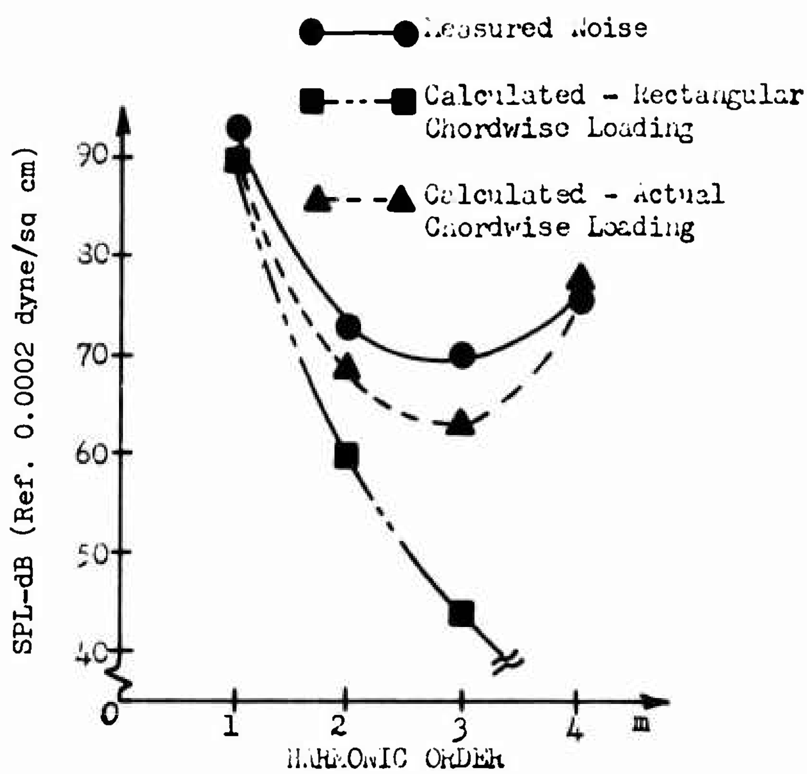
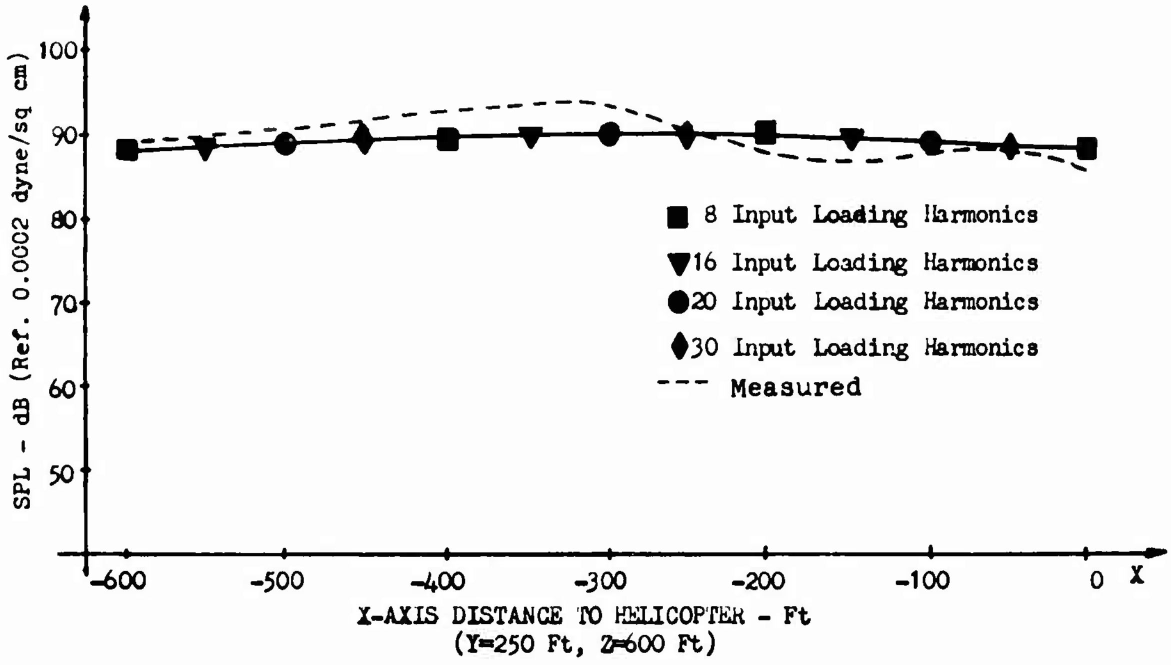
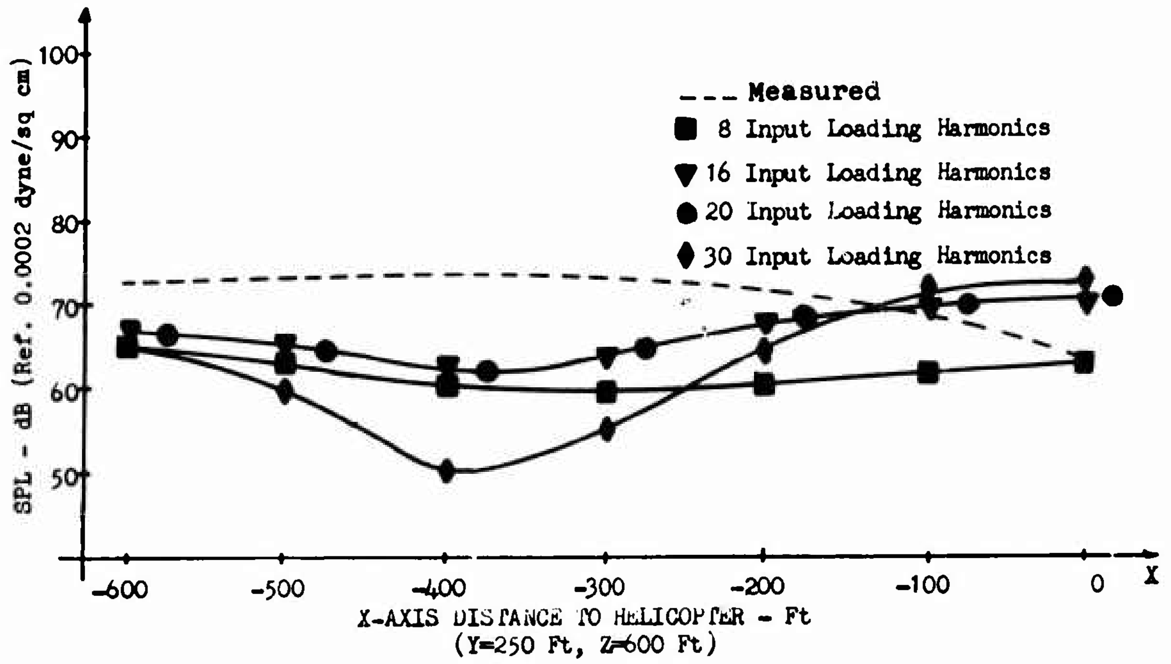


Figure 17. Effect of Chordwise Loading Distribution on Predicted Spectrum - 165 Knots, Low Wing Lift (X = -400 ft, Y = 250 ft, Z = 600 ft).

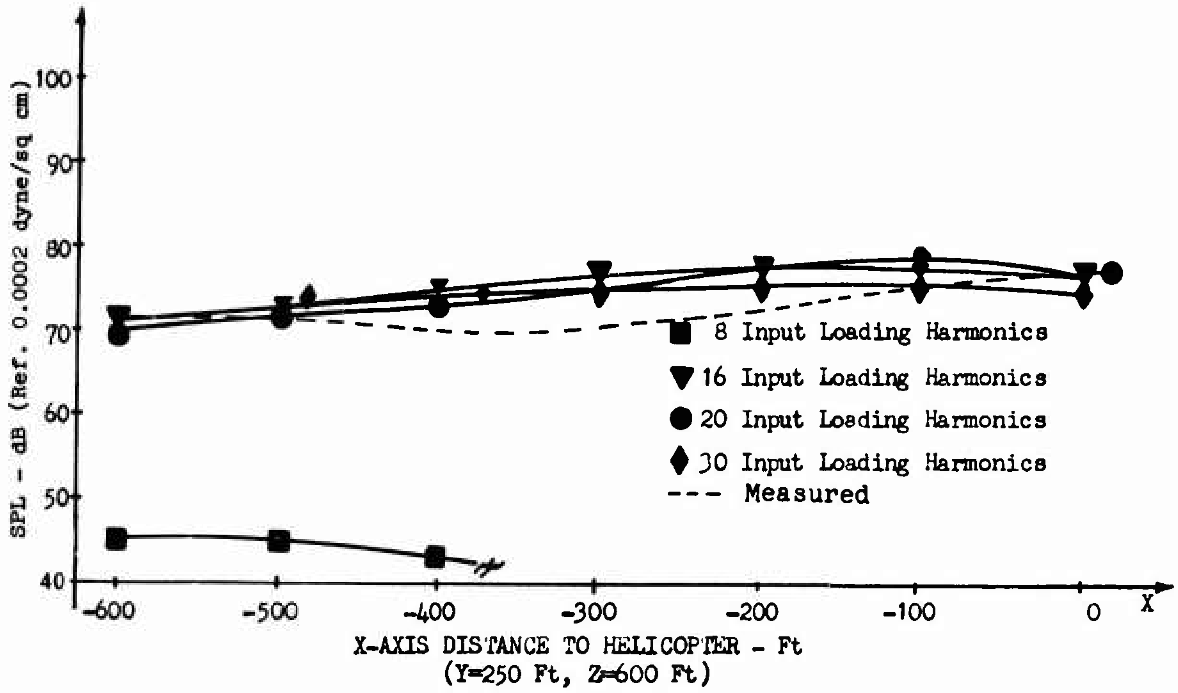


a. Calculated First Noise Harmonic.

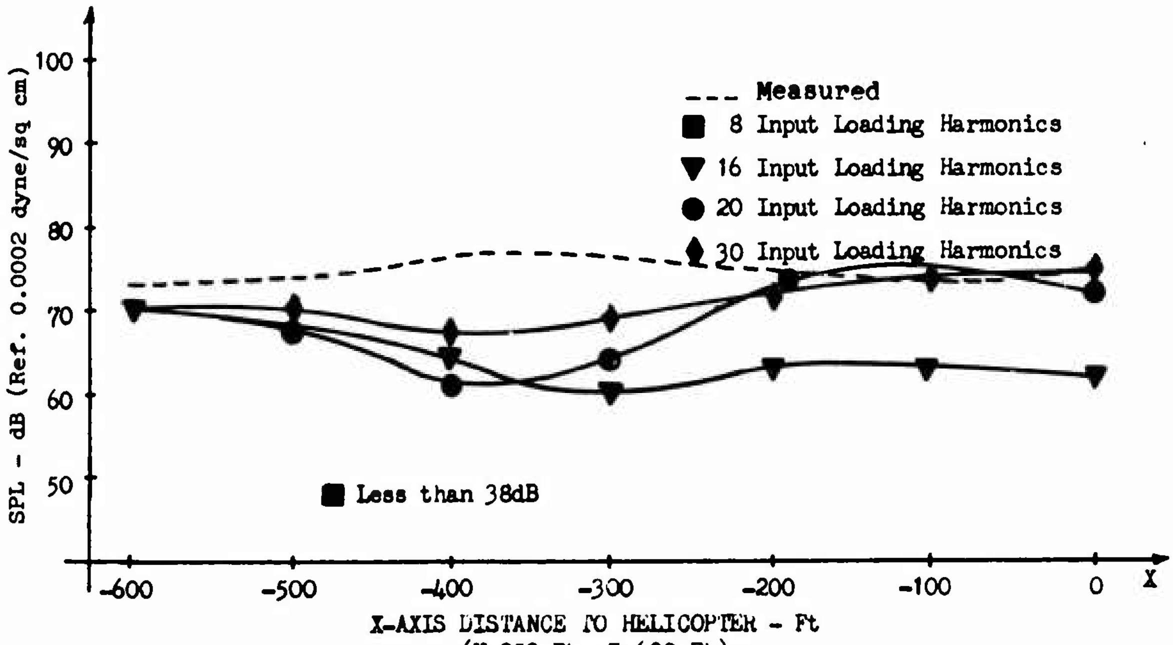


b. Calculated Second Noise Harmonic.

Figure 18. Loading Harmonic Effect,
Rectangular Chordwise Loading.

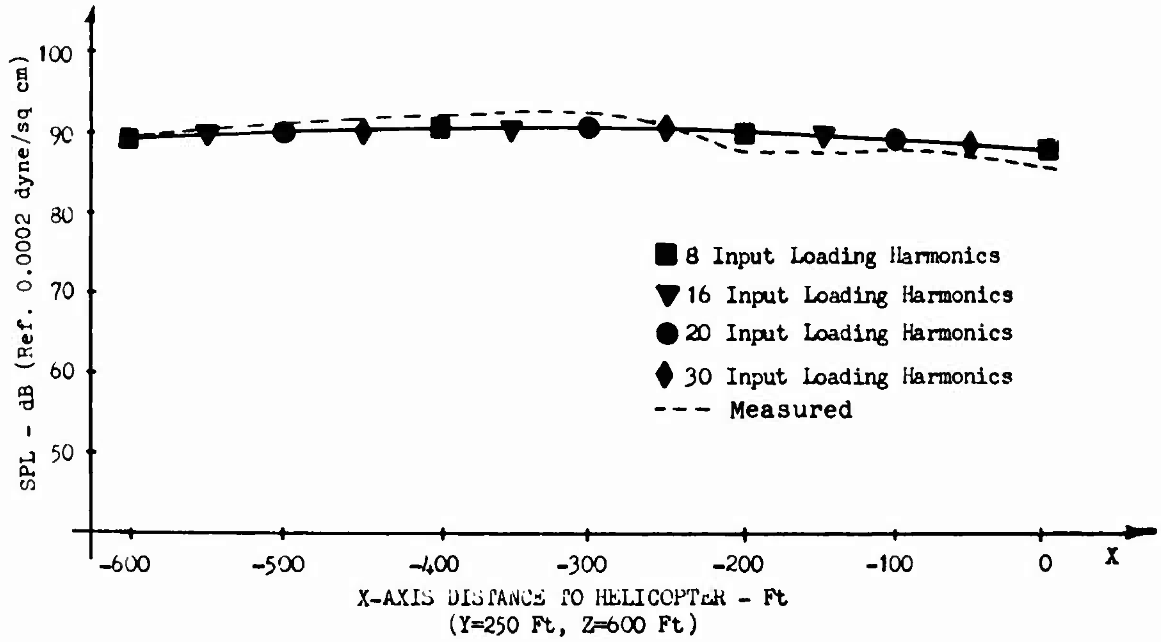


c. Calculated Third Noise Harmonic.

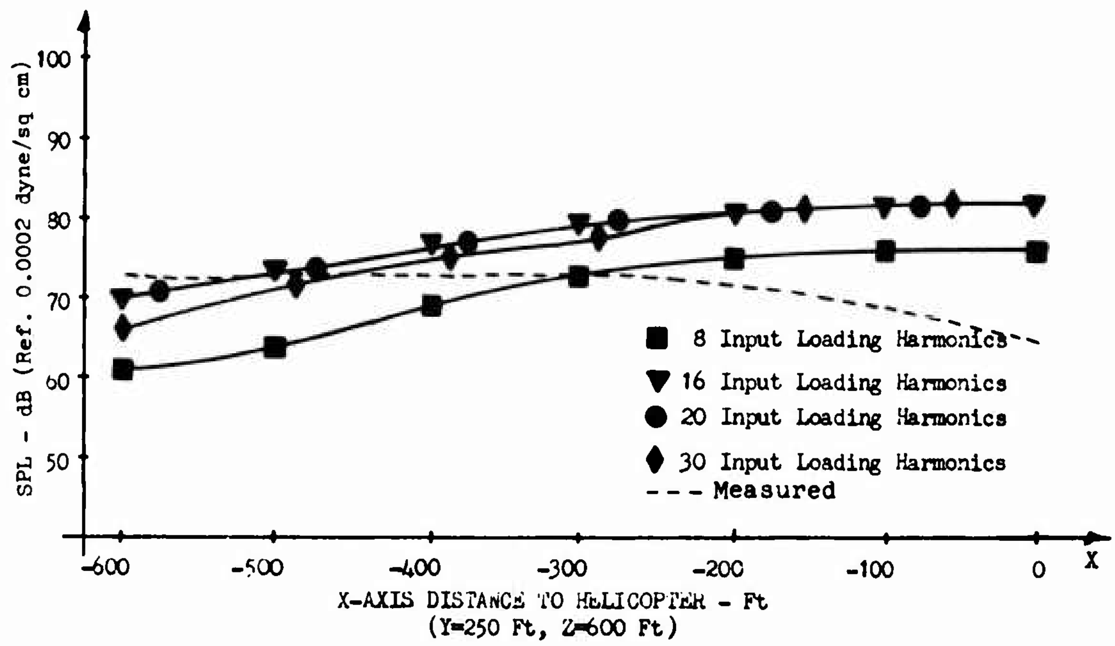


d. Calculated Fourth Noise Harmonic.

Figure 18. Concluded.

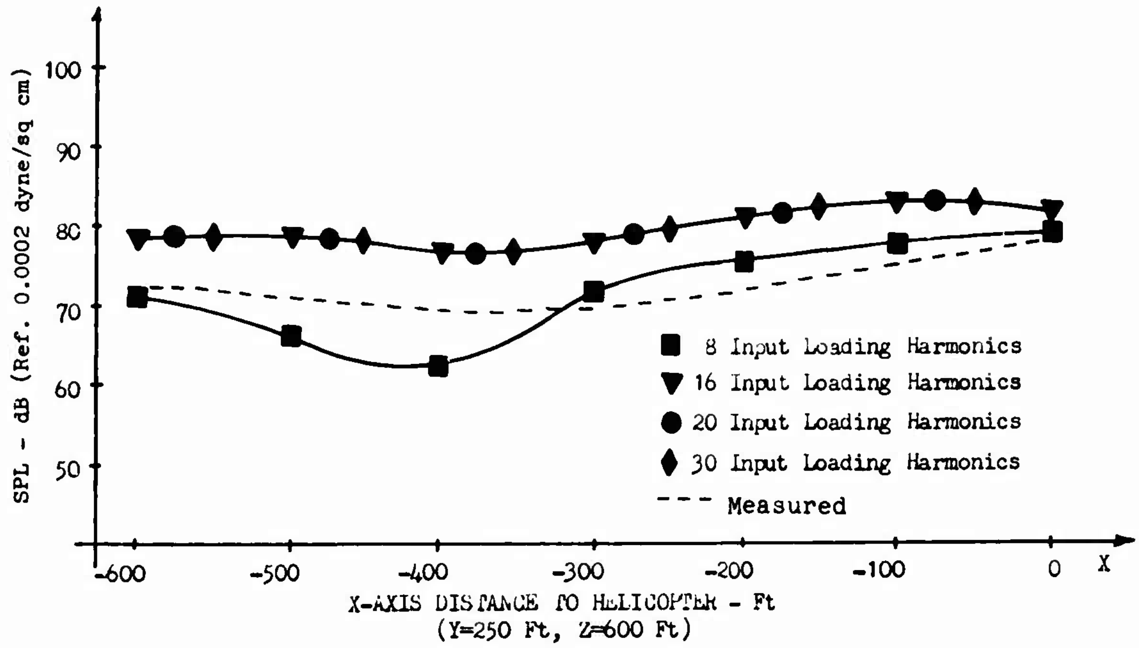


a. Calculated First Noise Harmonic.

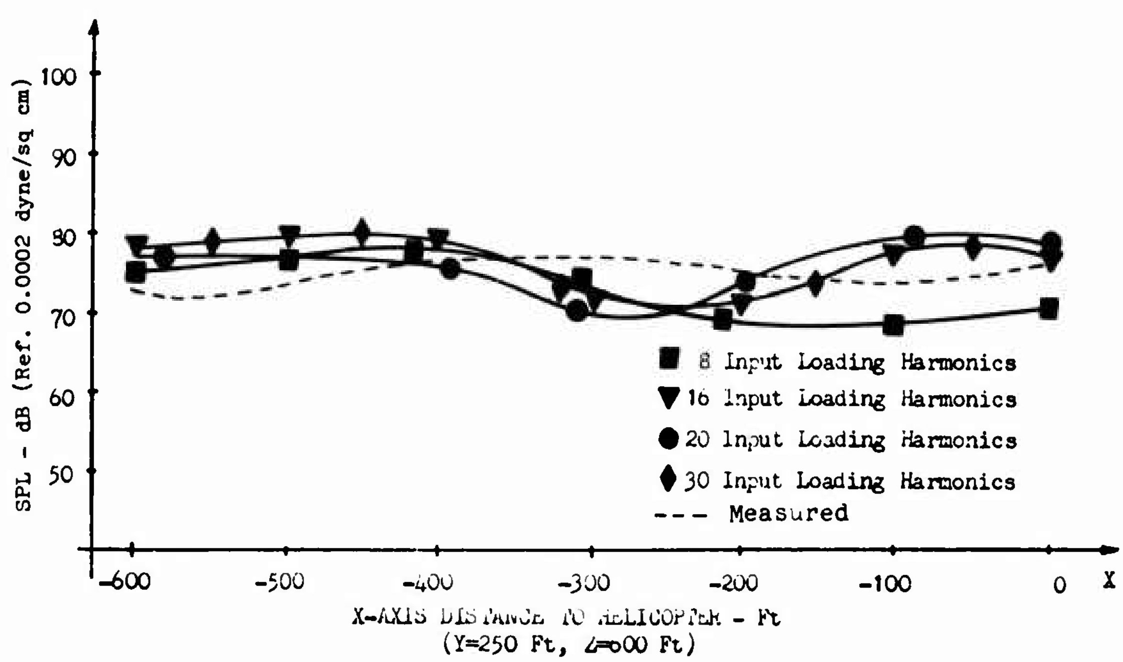


b. Calculated Second Noise Harmonic.

Figure 19. Loading Harmonic Effect,
Actual Chordwise Loading.



c. Calculated Third Noise Harmonic.



d. Calculated Fourth Noise Harmonic.

Figure 19. Concluded.

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APPENDIX I
FOURIER EXPANSION OF PRESSURE PULSE AT (r, ψ)

The Fourier expansion representing the periodic variation of a force $\vec{F}$ or a pressure $\vec{L}$ over a point (r, ψ) in the rotor disc due to a blade passing over it is

$$\vec{F}(r,\psi,t) = \frac{1}{b}\vec{L}(r,\psi,t) = \sum_{m=0}^{\infty} \vec{g_m}(r,\psi)\cos m\omega t + \vec{h_m}(r,\psi)\sin m\omega t \tag{17}$$

for which the solutions for the amplitude coefficients $\vec{g_m}$ and $\vec{h_m}$ are

$$\vec{g_m} = \frac{2}{T}\int_{-T/2}^{T/2} \frac{1}{b}\vec{L}(r,\psi,t)\cos\frac{2m\pi t}{T}\,dt \tag{18a}$$

and

$$\vec{h_m} = \frac{2}{T}\int_{-T/2}^{T/2} \frac{1}{b}\vec{L}(r,\psi,t)\sin\frac{2m\pi t}{T}\,dt \tag{18b}$$

where T is the period of the pressure variation. This equals the time interval between the passage of successive blades over (r, ψ) or

$$T = \frac{2\pi}{n\Omega} \tag{19}$$

where Ω = rotational velocity

Since the pressure variation occurs only as a blade passes over (r, ψ), the duration is

$$\tau = \frac{a}{\Omega r} \tag{20}$$

where a = blade chord length
r = distance from center of rotation to the element at (r, ψ)

Substituting for T and τ in the expressions for $\vec{g_m}$ and $\vec{h_m}$ yields

$$\vec{g_m} = \frac{n\Omega}{\pi b}\int_{-\frac{a}{2\Omega r}}^{\frac{a}{2\Omega r}} \vec{L}(r,\psi,t)\cos mn\Omega t\,dt \tag{21a}$$

and

$$\vec{h_m} = \frac{n\Omega}{\pi b}\int_{-\frac{a}{2\Omega r}}^{\frac{a}{2\Omega r}} \vec{L}(r,\psi,t)\cos mn\Omega t \, dt \qquad (21b)$$

It is convenient to express the time t in terms of azimuth angle ψ from

$$\psi = \Omega t \; ; \; \psi = 0 \text{ when } t = 0$$

$$\Delta\psi = \Omega\tau$$

$$dt = \frac{d\psi}{\Omega} \qquad (22)$$

so that

$$\cos mn\Omega t \, dt = \frac{\cos mn\psi}{\Omega} d\psi \qquad (23)$$

$$\sin mn\Omega t \, dt = \frac{\sin mn\psi}{\Omega} d\psi$$

and the limits of integration become $\pm\Delta\psi/2$ instead of $\pm\tau/2$. Substitution into Equation (21) gives the final expressions for the Fourier coefficients:

$$\vec{g_m}(r,\psi) = \frac{n}{\pi b}\int_{-a/2r}^{a/2r} \vec{L}(r,\psi)\cos mn\psi \, d\psi \qquad (24a)$$

and

$$\vec{h_m}(r,\psi) = \frac{n}{\pi b}\int_{-a/2r}^{a/2r} \vec{L}(r,\psi)\sin mn\psi \, d\psi \qquad (24b)$$

Since each element $(dr, r d\psi)$ at each (r, ψ) will radiate only when a blade passes over it, the rotation of the blade introduces a time phasing of one element relative to another element at a different azimuthal location in the rotor disc. This phasing can be included by modifying the argument of the cosine and sine in Equation (17) to include (ψ/Ω). The time (t) then becomes $(t-\psi/\Omega)$. Substitution for $\vec{g_m}$ and $\vec{h_m}$ into (1) and including the phasing yields the final form of the Fourier expansion for $\vec{F}(r,\psi,t)$ given in Equation (5). The steady component corresponding to $m = 0$ is ignored since it is not an acoustic signal.

APPENDIX II
CALCULATION OF PARTIAL DERIVATIVES

The integral solution for the sound pressure P requires the evaluation of six partial derivatives.

The first to appear is

$$g_{mx}\frac{\partial}{\partial x}\left(\frac{\cos m\omega(t-\frac{\psi}{\Omega}-\frac{s}{c})}{s}\right) \quad (25a)$$

which can be written as

$$g_{mx}\cos m\omega(t-\frac{\psi}{\Omega}-\frac{s}{c})\frac{\partial}{\partial x}(\frac{1}{s})+\frac{g_{mx}}{s}\frac{\partial}{\partial x}\cos m\omega(t-\frac{\psi}{\Omega}-\frac{s}{c}) \quad (25b)$$

Now

$$\frac{\partial}{\partial x}(\frac{1}{s})=-\frac{1}{s^2}\frac{\partial s}{\partial x}=-(\frac{x-r\cos\psi}{s^3}) \quad (25c)$$

and

$$\frac{\partial}{\partial x}\cos m\omega(t-\frac{\psi}{\Omega}-\frac{s}{c})=\frac{m\omega}{cs}(x-r\cos\psi)\sin m\omega(t-\frac{\psi}{\Omega}-\frac{s}{c}) \quad (25d)$$

so that

$$g_{mx}\frac{\partial}{\partial x}\left(\frac{\cos m\omega(t-\frac{\psi}{\Omega}-\frac{s}{c})}{s}\right)=g_{mx}\left\{-\frac{(x-r\cos\psi)}{s^3}\cos m\omega(t-\frac{\psi}{\Omega}-\frac{s}{c})\right.$$

$$\left.+\frac{m\omega}{cs^2}(x-r\cos\psi)\sin m\omega(t-\frac{\psi}{\Omega}-\frac{s}{c})\right\} \quad (25e)$$

The other derivatives are evaluated in the same fashion with the results

$$g_{my}\frac{\partial}{\partial y}\left(\frac{\cos m\omega(t-\frac{\psi}{\Omega}-\frac{s}{c})}{s}\right)=g_{my}\left\{-\frac{(y-r\sin\psi)}{s^3}\cos m\omega(t-\frac{\psi}{\Omega}-\frac{s}{c})\right.$$

$$\left.+\frac{m\omega}{cs^2}(y-r\sin\psi)\sin m\omega(t-\frac{\psi}{\Omega}-\frac{s}{c})\right\} \quad (26)$$

and

$$g_{mz}\frac{\partial}{\partial z}\left(\frac{\cos m\omega(t-\frac{\psi}{\Omega}-\frac{s}{c})}{s}\right)=g_{mz}\left\{-\frac{z}{s^3}\cos m\omega(t-\frac{\psi}{\Omega}-\frac{s}{c})\right.$$

$$\left.+\frac{m\omega}{cs^2}z\sin m\omega(t-\frac{\psi}{\Omega}-\frac{s}{c})\right\} \qquad (27)$$

and

$$h_{mx}\frac{\partial}{\partial x}\left(\frac{\sin m\omega(t-\frac{\psi}{\Omega}-\frac{s}{c})}{s}\right)=h_{mx}\left\{-\frac{(x-r\cos\psi)}{s^3}\sin m\omega(t-\frac{\psi}{\Omega}-\frac{s}{c})\right.$$

$$\left.-\frac{m\omega}{cs^2}(x-r\cos\psi)\cos m\omega(t-\frac{\psi}{\Omega}-\frac{s}{c})\right\} \qquad (28)$$

and

$$h_{my}\frac{\partial}{\partial y}\left(\frac{\sin m\omega(t-\frac{\psi}{\Omega}-\frac{s}{c})}{s}\right)=h_{my}\left\{-\frac{(y-r\sin\psi)}{s^3}\sin m\omega(t-\frac{\psi}{\Omega}-\frac{s}{c})\right.$$

$$\left.-\frac{m\omega}{cs^2}(y-r\sin\psi)\cos m\omega(t-\frac{\psi}{\Omega}-\frac{s}{c})\right\} \qquad (29)$$

and

$$h_{mz}\frac{\partial}{\partial z}\left(\frac{\sin m\omega(t-\frac{\psi}{\Omega}-\frac{s}{c})}{s}\right)=h_{mz}\left\{-\frac{z}{s^3}\sin m\omega(t-\frac{\psi}{\Omega}-\frac{s}{c})\right.$$

$$\left.\frac{m\omega}{cs^2}z\cos m\omega(t-\frac{\psi}{\Omega}-\frac{s}{c})\right\} \qquad (30)$$

Representing the components of $\vec{g}_m$ and $\vec{h}_m$ by their Cartesian components in Equations (25) through (30) and introducing these expressions into the integral equation for P_m (Equation (7)) allows the term

$$q_1 \equiv (x-r\cos\psi)\sin\beta\sin\psi-(y-r\sin\psi)\sin\beta\cos\psi+z\cos\beta \qquad (31)$$

to be isolated to simplify the equation. The result of factoring out q_1 and performing the integration over db is given in Equation (10).

APPENDIX II
NOISE PREDICTION COMPUTER PROGRAM

Equation (16) has been programmed in FORTRAN V for the UNIVAC 1108 digital computing system. The program contains the analysis of Reference 1 as a subroutine. The program calculates the root-mean-square SPL at any field point that is more than one radius away from the center of rotation of the main rotor. The analysis developed during the present study calculates the SPL from the actual chordwise distribution of differential pressure on the blades while the Reference 1 analysis calculates the SPL based on a rectangular chordwise distribution.

Aerodynamic data in the form of azimuthal harmonics of differential pressure are the basic input to the program. Additional input parameters describe the geometry of the rotor system and the operating conditions of rotor rotational speed and altitude above the ground.

The differential pressure harmonics are summed to produce a chordwise pressure distribution for up to 288 azimuthal points at each of five instrumented radial stations. The values of $\overline{\vec{g}_m}$ and $\overline{h_m}$ are then determined for each azimuthal point at each of the five instrumented radial stations. In order to integrate for $\overline{\vec{g}_m}$ and $\overline{h_m}$ numerically, the chordwise pressure distribution is divided into 41 points along the chord. After these parameters are calculated, an interpolation routine is used to determine the values of $\overline{\vec{g}_m}$ and $\overline{h_m}$ at 10 or 20 equally spaced radial stations. Then the required calculations are performed to determine the final integrands, and the double integrations are performed using a standard trapezoidal integration routine.

APPENDIX IV
AERODYNAMIC DATA

RECORDING AND PROCESSING INSTRUMENTATION

All of the flight data used in this study were recorded with instrumentation on board the NH-3A rather than with radio telemetry techniques. The general arrangement of the test aircraft is shown in Figure 20. Reference 4 contains the details of the mounting of the instrumentation.

Pressure Transducers

Pressure transducers manufactured by Scientific Advances, Inc., were mounted on one main rotor blade. Differential pressures were measured directly wherever possible with model SA-SD-M-7F transducers with ranges of ±2 psid, ±5 psid, or ±10 psid. Wherever blade structural requirements precluded use of a differential gage, two absolute pressure gages with a range from 3 psia to 18 psia were used (model SA-SA-M-7F). Differential pressures were obtained from pairs of absolute gages by algebraic addition after data reduction rather than by direct electronic summation of the gage output signals. This procedure avoids errors that would arise from differences in pressure and temperature-tracking characteristics between paired transducers. The locations and ranges of absolute and differential pressure gages on the main rotor blade are summarized in Table I. Spanwise transducer locations are specified from root to tip, and chordwise locations are specified from leading edge to trailing edge.

Frequency response of the pressure-measurement instrumentation was limited by the narrow-band F. M. multiplex recording system in the aircraft and by the low-pass filters used with the F. M. discriminators in the data reduction facility, not by the transducers. The narrow-band F.M. restricts the recorded data to below approximately 300 Hz, and the low-pass filters attenuate the signal as frequency increases above 60 Hz. At 102 Hz (20th harmonic), the amplitude correction was 3.3 dB. The response of the pressure transducers is flat to at least 1 kilocycle, according to the manufacturer's specifications.

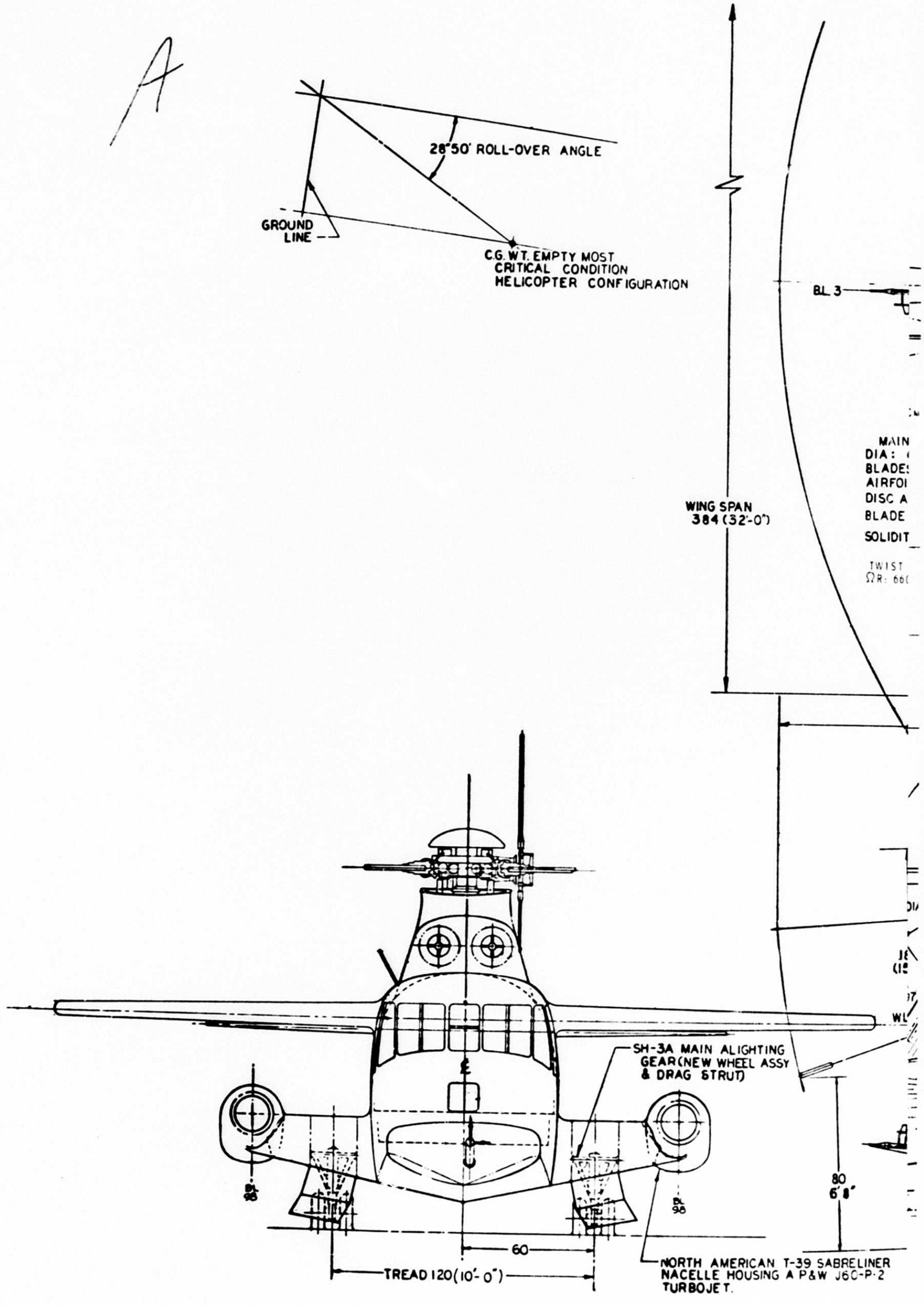
Blade Pitch Angulators

A Baldwin-Lima-Hamilton Angular Position Transducer, Model 236, was used to measure the impressed pitch angle (collective plus cyclic pitch) of the instrumented rotor blade. The angulator is temperature-compensated and linear over a range of ±20 degrees.

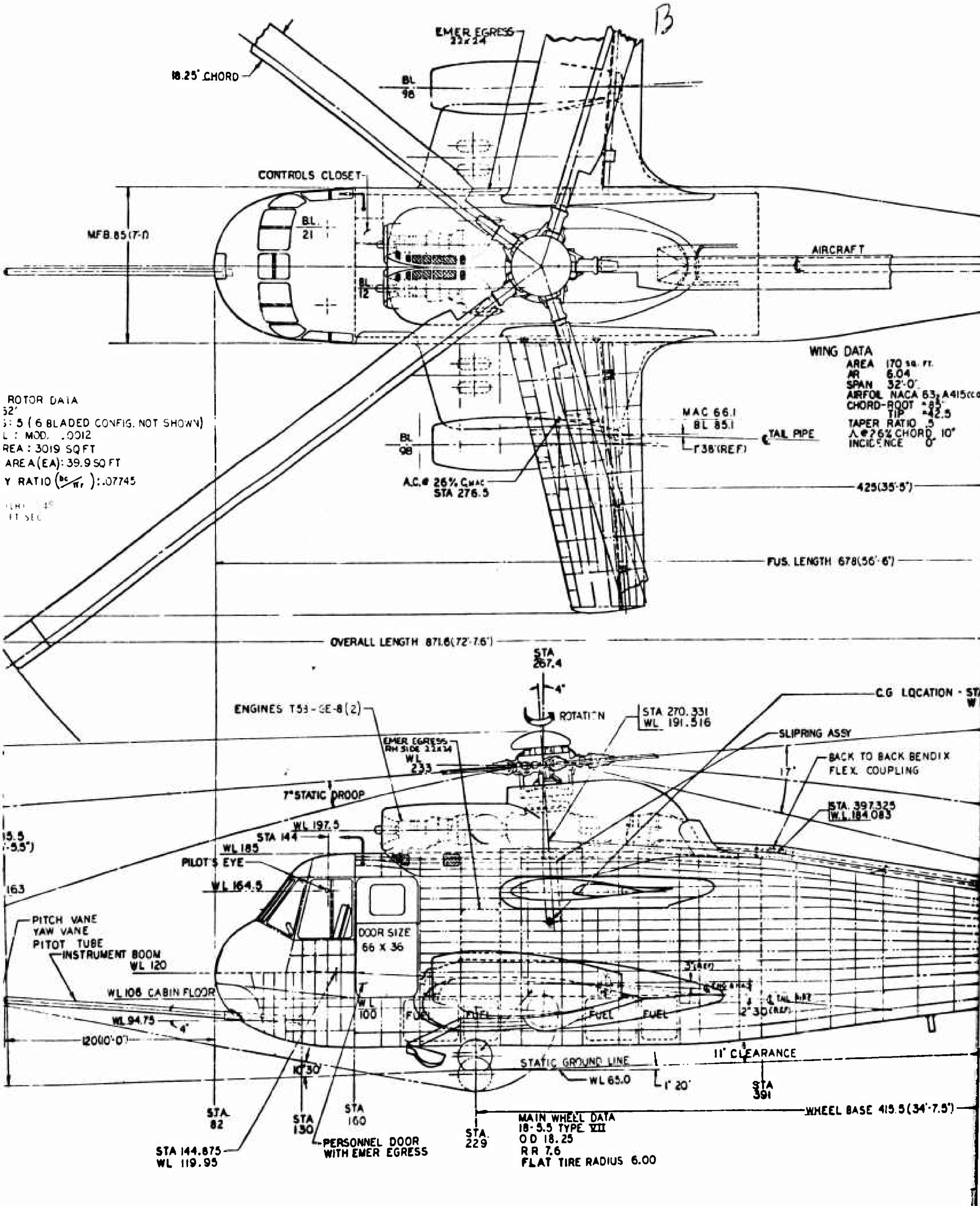
Airborne Data-Recording System

All dynamic data were recorded on magnetic tape using a 14-track narrow-band F.M. system. Relative phasing was preserved on all recording tracks. Quasi-static data (altitude, airspeed, etc.) were recorded on photographic film using standard photopanel techniques.

A



28°50' ROLL-OVER ANGLE
GROUND LINE
C.G. WT. EMPTY MOST CRITICAL CONDITION HELICOPTER CONFIGURATION
BL 3
MAIN
TWIST
WING SPAN 384 (32'-0")
WL
SH-3A MAIN ALIGHTING GEAR (NEW WHEEL ASSY & DRAG STRUT)
BL 98
BL 98
80 6'8"
60
TREAD 120 (10'-0")
NORTH AMERICAN T-39 SABRELINER NACELLE HOUSING A P&W J60-P-2 TURBOJET.



B
EMER EGRESS 22 x 24
18.25" CHORD
BL 98
CONTROLS CLOSET
MFB 85 (7-1)
BL 21
BL 12
AIRCRAFT
WING DATA
AREA 170 SQ. FT.
AR 6.04
SPAN 32'-0"
CHORD-ROOT 85"
TIP 42.5
TAPER RATIO .5
INCIDENCE 0°
ROTOR DATA
5 (6 BLADED CONFIG. NOT SHOWN)
REA: 3019 SQ FT
AREA (EA): 39.9 SQ FT
Y RATIO: .07745
MAC 66.1
BL 85.1
TAIL PIPE
BL 98
A.C. @ 26% C_{MAC} STA 276.5
425 (35'-5")
FUS. LENGTH 678 (56'-6")
OVERALL LENGTH 871.6 (72'-7.6")
STA 267.4
4°
ROTATION
STA 270.331
WL 191.516
C.G. LOCATION
ENGINES T58-GE-8 (2)
EMER EGRESS RH SIDE 22 x 24
WL 233
SLIPRING ASSY
BACK TO BACK BENDIX FLEX. COUPLING
17°
7° STATIC DROOP
STA 397.325
WL 184.083
WL 197.5
STA 144
WL 185
PILOT'S EYE
WL 164.5
163
PITCH VANE
YAW VANE
PITOT TUBE
INSTRUMENT BOOM
WL 120
DOOR SIZE 66 X 36
WL 108 CABIN FLOOR
WL 100
FUEL
FUEL
FUEL
FUEL
WL 94.75
4°
120 (10'-0")
11° CLEARANCE
STATIC GROUND LINE
WL 65.0
1° 20'
10° 30'
STA 391
STA 82
STA 130
STA 160
STA 229
WHEEL BASE 415.5 (34'-7.5")
MAIN WHEEL DATA
18-5.5 TYPE VII
O D 18.25
R R 7.6
FLAT TIRE RADIUS 6.00
STA 144.875
WL 119.95
PERSONNEL DOOR WITH EMER EGRESS

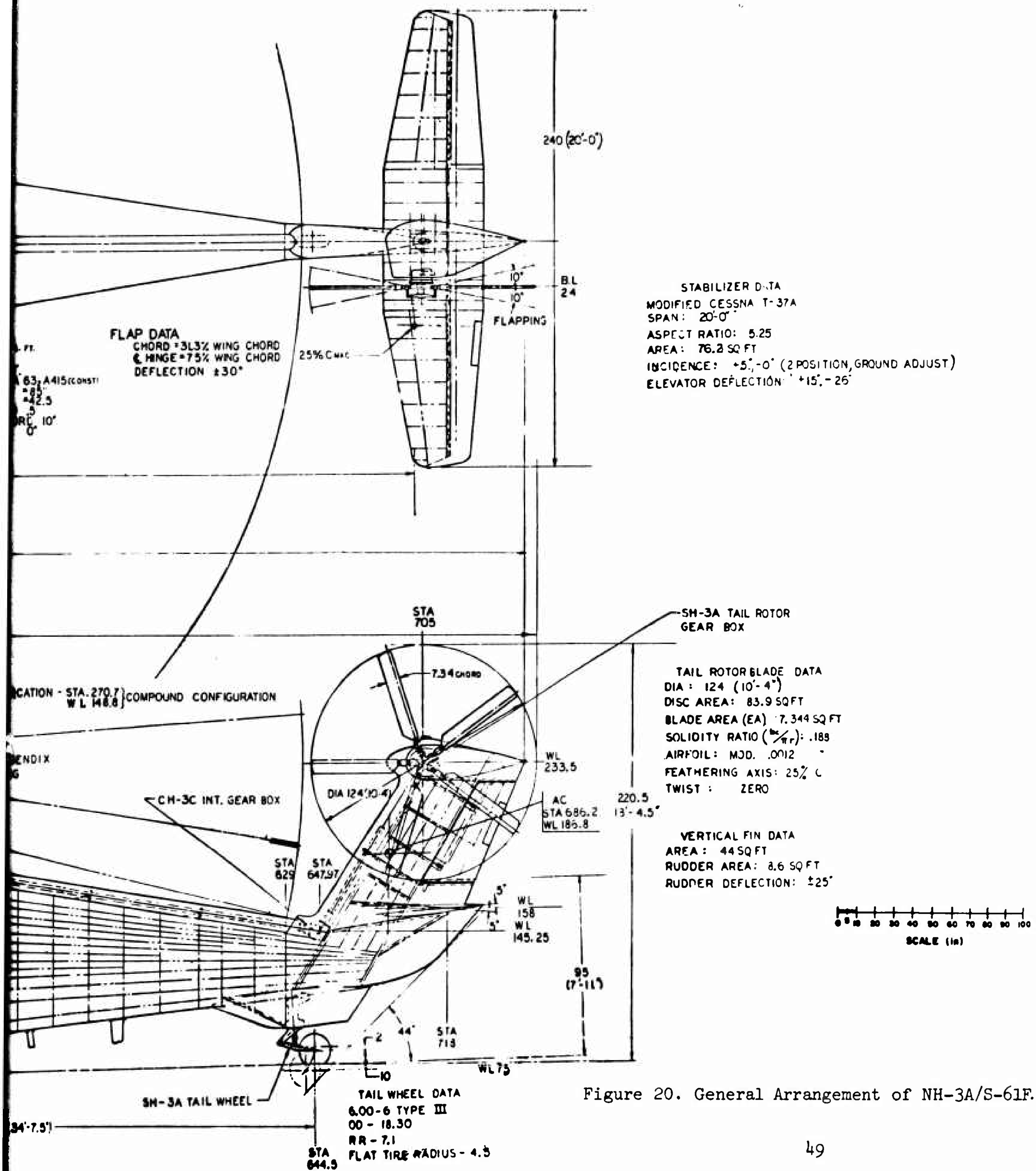


Figure 20. General Arrangement of NH-3A/S-61F.

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TABLE I. PRESSURE TRANSDUCER LOCATION AND RANGE

PERCENTAGE CHORDWISE	PERCENTAGE SPANWISE 40	75	85	95	98
4.2	3-18 PSIA	3-18 PSIA	3-18 PSIA	3-18 PSIA	±10 PSID
15.8	3-18 PSIA	3-18 PSIA	3-18 PSIA	3-18 PSIA	± 5 PSID
30.0	3-18 PSIA	3-18 PSIA	3-18 PSIA	3-18 PSIA	± 5 PSID
60.0	± 2 PSID	± 2 PSID	± 2 PSID	± 2 PSID	± 2 PSID
91.0	± 2 PSID	± 2 PSID	± 2 PSID	± 2 PSID	± 2 PSID

Calibration of Pressure Transducers

Pressure transducers were calibrated by determining the pressure that corresponded to a known resistance change in the measurement bridge. The bridge resistance was changed by adding a precision resistor to the measurement circuit, hence the resistance calibration became known as an R-cal. Pressure then was applied by clamping a chamber over each sensor so that the pressure could be varied to duplicate the effect of the R-cal resistance change. This technique was used at the beginning and end of the overall flight program for this study and Reference 4, while the R-cal technique was used before and after the individual flights. R-cal values obtained at the end of the NH-3A flight program agreed very well with the values obtained at the outset. The basic response characteristics of each transducer - resistances, linearity, hysteresis, and temperature effects - were determined by the manufacturer under environmental conditions specified by Sikorsky Aircraft.

Calibration of Angulators

The Norden Division of United Aircraft Corporation performed the angulator calibrations under Sikorsky supervision. An angular position table was used to determine the angle-to-output-voltage correspondence for clockwise and counterclockwise rotation. Pre- and post-flight calibration on the aircraft consisted of recording the angulator output for several known impressed pitch positions of the instrumented blade.

DATA REDUCTION

Analog-to-Digital Conversion

The dynamic data recorded in analog form by the airborne system were converted to digital form for use in the rotational noise prediction computer program. The analog-to-digital conversion system (A/D) processed 10 data channels (1 recording track) simultaneously. The F.M. multiplex output from each channel was fed through a discriminator whose output was connected to a 60 Hz low-pass filter. The signal coming through the filter then passed into a normalizing amplifier to provide a full-scale range of 10 volts for each channel. A solid-state multiplexer, with sample and hold amplifiers, passed the normalized signal to the A/D converter that sampled the data at 450 samples per second. An external oscillator controlled the sampling rate.

Since the acoustic computer program was designed to accept digital data from tapes in 2.5-degree azimuth steps, an editing program was used to provide 144 points per revolution of the main rotor. The editing program also corrected for the phase shift introduced by the low-pass filters and data processing electronics. This correction amounted to approximately 6 degrees of azimuth for a rotor speed of 204 rpm.

System Accuracy

The following description of system accuracy includes both airborne and

ground station apparatus. Accuracy is expressed in terms of percentage of full scale.

Absolute pressure transducers, 3-18 psia range: vibratory 3%, steady 6%.

Differential pressure transducers, ± 2 psi range; vibratory 5%, steady 11%.

Differential pressure transducers, ± 5 psi range; vibratory 5%, steady 10%.

Differential pressure transducers, ± 10 psi range; vibratory 5%, steady 10%.

Blade pitch angle; combined steady plus vibratory 2%.

APPENDIX V
FLIGHT DATA

Tables II through VI contain differential pressure and blade pitch angle data in harmonic form. The burst number identifies the flight conditions on magnetic tape. Span locations are 40, 75, 85, 95, and 98 percent of the blade radius from root to tip. Chord locations are 4.2, 15.8, 30, 60, and 91 percent chord from leading edge to trailing edge. The harmonics are for a positive series comprised of a steady plus cosine and sine components.

Read the pressure harmonics like a book, left to right and line by line. Consider the first span and chord location in Table II as an example. The cosine and sine components of the first harmonic in decimal format are (-.90449, .60821), and the components of the 29th harmonic are (.0015424, -.0000819).

Table VI describes the trim of the aircraft for each flight condition. Large tolerances are assigned to values for total wing/fuselage lift, main rotor thrust, and main rotor drag. The strain gages that measured the lift provided by each wing were totally unreliable, so wind tunnel test values of a model NH-3A were used to estimate wing/fuselage lift. The large indicated tolerance indicates that as of this writing, wind tunnel and full-scale tests had not been correlated for combined wing/fuselage lift. Main rotor thrust was obtained from strain gages on the main shaft, but problems with converting data from rotating to fixed reference resulted in large tolerances here. Main rotor drag was calculated as the difference between the horizontal components of main rotor thrust plus auxiliary jet thrust (both from flight test) and total airframe drag (estimated from wind tunnel data).

TABLE II. AERODYNAMIC DATA - 165 KNOTS, HIGH WING LIFT

```
BURST NO. = 12           *** ROTOR NOISE PUNCHED OUTPUT ***
BLADE PITCH HARMONICS
 7.2161+00 7.8865-01-9.1138+00  (COLLECTIVE,LONGITUDINAL,LATERAL RESPECTIVELY)
DIFFERENTIAL PRESSURE HARMONICS FOR 5 CHORD STATIONS AT EACH OF THE 5 SPANS
(MEASURING FROM THE LEADING EDGE AND THE BLADE ROOT RESPECTIVELY).
SPAN 1  CHORD 1        STEADY=  6.8894-01
COSINE COEFFICIENTS
-9.0449-01 3.0046-01 1.0009-01-7.7209-03-7.6139-02-7.4964-02 5.5406-03-6.2866-03
 2.1759-02-1.9855-02-6.9524-03-4.5632-03-7.0044-03 6.2634-03 1.6635-02 8.9284-03
-2.1911-03-2.4317-03-1.9800-03-6.5192-03 5.0141-03 4.6032-04 5.6984-03 1.2247-03
 3.6320-03-1.5278-03-3.0435-03-2.3595-03 1.5424-03 1.3138-04
SINE COEFFICIENTS
 6.0821-01-5.0733-01 4.5137-01 1.4115-01 2.2990-01 8.7061-03 4.7375-02-2.8509-02
 2.2499-02-7.4950-03 1.0879-02 1.5018-02 2.3247-02 4.2093-03 6.4079-03 1.4598-03
-3.3077-03-8.4306-03-4.1551-03 4.5860-03 3.2203-03 6.2838-03 2.8294-03-2.8029-03
-1.8281-03 2.8119-03 8.3716-04-9.5024-04-8.1900-05 5.3612-04
SPAN 1  CHORD 2        STEADY=  3.6804-01
COSINE COEFFICIENTS
-4.2226-01 1.3859-01 5.0904-02-3.0001-03-4.5309-02-4.1925-02 3.9490-03-4.6291-03
 1.0045-02-1.4179-02-4.7752-03-2.5890-03-9.9037-04 1.4853-03 7.0561-03 8.7771-04
-1.6734-03-5.5460-03 1.2250-03-1.3731-03 2.7815-03 2.8034-03 4.7934-04 2.4986-03
-8.1580-04-1.2219-03 1.9688-04-8.3968-04 2.7286-04-7.9425-04
SINE COEFFICIENTS
 4.3222-01-2.9708-01 1.8972-01 6.6294-02 1.1125-01 6.0240-03 2.3056-02-1.3224-02
 1.0455-02 5.2315-04 8.1772-03 6.8987-03 1.2878-02 2.5507-03-4.1075-04-4.8311-04
-2.4162-03-2.9721-03-1.4314-03 8.5765-04 1.7915-03 7.0916-04-2.2407-03-1.8797-03
-1.1007-03 1.2156-03-1.1194-04-4.9432-04 8.7877-05-7.3659-04
SPAN 1  CHORD 3        STEADY=  1.1969-01
COSINE COEFFICIENTS
-3.3413-01 8.8309-02 1.2383-02-8.2656-03-3.0101-02-2.4531-02-1.1044-04-5.1765-03
 3.3902-03-1.0812-02-4.1374-03-3.4458-04 1.4501-03 9.2501-04 5.7968-03 1.3556-03
-2.0131-03-1.3924-03-6.5968-04-1.2993-03-5.0430-04 1.5854-04-6.2381-05-1.2124-03
 1.1545-04 5.4092-04-1.1356-04-1.4119-03-1.3259-05-9.1801-05
SINE COEFFICIENTS
 2.0743-01-2.4056-01 8.2647-02 2.2793-02 6.0716-02 4.1832-03 1.2242-02-1.1905-02
 7.7257-03 2.6791-03 5.0534-03 6.4325-04 5.2230-03 7.4179-04-4.8352-04-5.5988-04
-8.2113-04 9.1737-05 2.0484-04 2.1041-03 9.5702-04 7.6058-04 5.3934-05-3.0703-04
 1.0101-03 1.5001-03 1.3216-03 1.1692-03-6.2288-04 2.1019-04
SPAN 1  CHORD 4        STEADY= -9.3780-02
COSINE COEFFICIENTS
-9.9413-02 5.7200-02 7.7063-03-2.6743-04-1.1447-02-6.9983-03-1.8841-03-3.3496-03
-1.7639-03-7.6163-03-5.2836-03-1.2989-03-3.2944-05 2.1258-04 1.4708-03 1.3459-03
 1.1046-03-2.1866-04-3.2466-04-7.9954-04-4.2549-04-5.0157-04 3.9917-05-7.7233-04
-9.9082-04-6.2932-04-3.4238-04 2.7888-04 1.9289-04 1.1252-04
SINE COEFFICIENTS
 1.7653-02-9.8907-02 1.9611-02 1.0233-02 1.8359-02-6.6943-03-1.3718-03-3.3452-03
 1.0070-03-1.3820-03 2.2459-03 1.3082-03 3.3790-03 1.4949-03 1.7943-04-3.7400-04
-6.8290-04 1.5715-04-4.0248-04-5.4930-04 3.8313-05-8.0520-04-5.8357-04-4.6531-04
 5.5960-04 3.0524-04 4.3281-04 3.6073-04 3.0208-04 3.5013-05
SPAN 1  CHORD 5        STEADY= -4.4071-02
COSINE COEFFICIENTS
-5.6015-03 1.2001-02-1.0449-03-5.8683-03 5.3432-03 5.2512-03 9.2529-04-9.2894-04
-7.2051-04-3.6168-03-4.5995-03-2.5590-03-9.7871-04 3.2896-05 6.2533-05 4.0338-04
-8.5680-04 1.3998-04-1.4189-03-3.9731-04-1.4760-03-6.1619-04-5.9858-04-8.7002-04
```

TABLE II - Continued

```
-3.3699-04 1.4291-04 9.4492-04-8.9110-04 7.1152-04-5.5856-04
SINE COEFFICIENTS
 7.7399-02-2.9267-02-4.8742-03-7.3710-04 8.0190-03-3.6031-03-5.3875-03-5.4177-03
-2.9381-03-3.7238-03-1.8999-05-4.8598-04 8.5677-04 5.8794-04-6.1134-05-2.4747-04
-1.0108-03-4.2884-04-3.7307-04-7.6206-04 1.3538-04-3.1567-04 3.8412-04-8.9573-04
 1.4926-03-1.3277-04 2.0235-03 8.0813-04 3.7999-04 2.5177-04
SPAN 2  CHORD 1        STEADY=  1.9285+00
COSINE COEFFICIENTS
 2.7938-01 9.1052-01 2.8264-01-1.2181-01-2.3307-02 4.8051-03-9.2911-03-1.5145-02
 1.8395-02-1.6409-02-6.6203-03 2.3896-02 2.2405-03-1.3526-02 1.4521-03 3.3878-03
-1.5747-02-1.3413-02 2.0629-03 1.7347-02-1.7069-02 3.1299-03-1.3796-03-2.5102-03
 4.5263-03 1.2049-03-5.8511-04 3.2825-03-1.2291-03 1.4259-03
SINE COEFFICIENTS
-6.9655-03-2.3534-01 3.9859-01 1.1423-01 7.6500-02-2.8868-02 4.1702-02-3.4775-02
-1.8879-03 1.9970-02-1.2122-03 1.4146-03 2.3440-02 7.4128-04-1.3030-02 8.8141-03
 2.7487-03-5.5215-03-1.0966-02 2.0703-02 8.2375-03-9.7584-03 6.9882-03 5.9210-05
 5.7825-03-1.3247-03-2.5833-04-2.2348-04 8.5636-03 8.0506-03
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 7.3623-04-5.5665-04-3.6418-04-2.9389-03 1.1834-03-3.6913-03
SINE COEFFICIENTS
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 3.9120-03 2.1331-03 2.2423-05-1.4390-03 2.7074-03 2.5278-03
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-1.8350-03 2.6428-04 7.0194-04 5.0745-04-4.4364-04-5.7267-04
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TABLE II - Continued

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TABLE II - Continued

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-5.3649-01-1.2816-01-1.3382-01-5.5070-02 3.9850-02 2.5113-02-1.6849-02-1.7332-02
-1.3425-03-8.3792-05-2.2624-03 4.4378-03 4.3697-03 1.4257-03 6.2984-03 8.2434-03
 1.4708-03-2.1193-03-2.0812-03-1.3022-03-1.8749-03-1.7541-03-8.7089-04 3.3947-04
 1.6455-03 1.1346-03 3.5458-04-6.7913-04-1.4624-03 5.3025-04
SPAN 5  CHORD 5        STEADY= -4.3809-01
```

TABLE II - Concluded

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COSINE COEFFICIENTS
-1.3715-01-7.2803-02-5.4572-03 1.3564-02 8.1157-04-1.2038-02-3.2475-03 6.2095-03
 8.0081-03-7.2217-03-5.2212-03-3.1810-03-4.3749-04 3.1696-03-3.1578-04-2.7949-05
 7.4169-04-2.1859-03-7.1273-04-4.5699-04 1.1939-03 1.7032-03-1.1707-03-3.0377-04
 7.2973-05-1.7857-04-5.6249-04-8.1383-04 1.3012-05 9.5613-04
SINE COEFFICIENTS
-1.6806-03-1.4280-03-2.3416-02-1.4215-02 6.2773-03 1.0031-03-6.2208-03-6.9450-03
 1.0122-02 9.4656-03-3.2420-03-2.5333-03-4.1901-03-1.6714-05-8.0857-04-4.4405-04
 1.8981-03 8.3567-04 8.0222-05-1.3473-03-5.4818-04 9.2689-04 6.5403-04 5.2622-04
 4.2887-04 5.3649-04 9.3071-04-4.8768-04-8.5782-04 1.8024-04
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TABLE III. AERODYNAMIC DATA - 165 KNOTS, LOW WING LIFT

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BURST NO. = 13              *** ROTOR NOISE PUNCHED OUTPUT ***
BLADE PITCH HARMONICS
 8.5150+00 1.7878+00-9.1546+00  (COLLECTIVE,LONGITUDINAL,LATERAL RESPECTIVELY)
DIFFERENTIAL PRESSURE HARMONICS FOR 5 CHORD STATIONS AT EACH OF THE 5 SPANS
(MEASURING FROM THE LEADING EDGE AND THE BLADE ROOT RESPECTIVELY).
SPAN 1  CHORD 1         STEADY=  1.0363+00
COSINE COEFFICIENTS
-9.8263-01 5.9133-01 2.4036-01-1.1329-01-1.0611-01-5.3502-02 1.0455-02-7.4505-03
 2.8579-02-4.0167-02 7.3342-03-2.5565-02 3.1410-03-5.3812-03 2.5242-02 1.4416-02
-8.5494-03-2.6959-03 1.0258-03-1.1179-02
SINE COEFFICIENTS
 7.7656-01-6.8249-01 5.7926-01 2.5240-01 1.2384-01 2.5328-02 4.5821-02-1.0433-02
 1.1538-02-1.6755-03 8.9326-03 8.0200-03 4.3653-02-6.4534-03 1.9782-02-2.4191-03
-1.3892-03-1.9505-02-4.5409-03 4.9060-03
SPAN 1  CHORD 2         STEADY=  5.7707-01
COSINE COEFFICIENTS
-4.8362-01 2.6994-01 1.3409-01-5.6017-02-7.3457-02-2.3293-02 7.8033-03-7.2251-03
 1.6222-02-1.7960-02-1.0057-02 7.2644-04 5.7654-03-4.5792-03 1.9520-02 1.1607-03
-2.4882-03-1.9668-03-5.1161-03 1.3480-03
SINE COEFFICIENTS
 5.1175-01-3.7734-01 2.2282-01 1.3558-01 5.6567-02 9.7851-03 2.8522-02-1.2667-02
 1.4812-02 4.4341-03 1.8276-03 1.1454-02 8.7091-03 2.8809-03-3.9299-03-2.3434-03
 3.0453-03-1.3114-02 1.4091-03 4.8906-03
SPAN 1  CHORD 3         STEADY=  2.3444-01
COSINE COEFFICIENTS
-3.6099-01 1.7189-01 4.9981-02-2.3969-02-5.2198-02-1.2333-02-5.7960-04-2.1508-03
 8.9346-03-1.2080-02-7.2802-03 2.4674-03 2.1521-03-1.2510-03 6.6004-03 1.7574-04
-3.6061-03-2.0779-03-2.1906-03-4.6152-04
SINE COEFFICIENTS
 2.6526-01-3.0031-01 9.3589-02 5.8273-02 2.8389-02 1.3377-02 1.3645-02-1.0780-02
 3.7785-03 7.5013-03 4.3309-04 5.5634-03 5.6297-03 1.6125-03-1.5221-03 3.5343-03
-1.7575-03-2.6361-03 1.0569-03 1.6814-03
SPAN 1  CHORD 4         STEADY= -4.9016-02
COSINE COEFFICIENTS
-1.1094-01 8.3637-02 1.9119-02-8.1379-03-1.9951-02 7.0415-04-3.1862-03 1.9911-03
 7.0105-04-6.5628-03-4.0992-03 8.4521-04 6.8505-05 1.8452-03 1.7665-03 2.5802-03
 3.2159-04-9.4543-04-9.9428-04-3.0257-03
SINE COEFFICIENTS
 3.5763-02-1.2231-01 2.6333-02 2.9186-02 1.0332-02-4.3339-03 8.9812-04-6.2971-03
 1.6343-03 9.6645-04-1.1094-03 2.6144-03 3.2081-03 9.0401-04-1.5358-03 8.4280-05
-2.3103-03-4.3281-05-1.0256-03 2.6071-04
SPAN 1  CHORD 5         STEADY= -4.7925-02
COSINE COEFFICIENTS
-6.9048-03 1.9961-02-1.8405-03-1.1350-02 3.8156-03 1.0718-02-1.5727-03 5.5342-04
 1.4591-03-1.3698-03-4.7712-03-2.9174-03-1.3129-03 9.9344-04 2.8496-04 1.4984-03
 1.2527-03 9.5393-04-2.7987-04-6.3388-04
SINE COEFFICIENTS
 8.3695-02-3.3696-02-1.1692-02 4.1600-03 1.2237-02-8.4147-04-5.0161-03-4.3599-03
-1.8744-03-2.8690-03-1.9052-03 8.6467-04 2.5279-03 2.3253-04 4.2902-04 1.0954-04
-2.1603-03-8.5142-04-2.2462-03-1.1991-03
SPAN 2  CHORD 1         STEADY=  3.1274+00
COSINE COEFFICIENTS
 2.1224-01 1.5426+00 6.6397-01-3.2080-01-1.1690-02 1.1773-01-8.1816-02-1.3000-02
 7.7805-02-1.7345-02-6.4659-02 5.3865-02 4.4250-02-6.6473-02-5.7129-04 4.4052-02
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TABLE III - Continued

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-1.9970-02-2.2743-02 4.3680-02 1.1446-03
SINE COEFFICIENTS
-7.5279-02-7.5152-01 6.1609-01 1.5581-01-4.2627-02 1.1990-02 1.1056-01-5.9218-02
-6.6230-03 6.7363-02-1.0069-02-3.5895-02 5.6877-02 2.1659-02-5.2348-02 2.0926-02
 3.9003-02-5.3039-02-1.8619-02 5.2788-02
SPAN 2  CHORD 2        STEADY=  2.3189+00
COSINE COEFFICIENTS
 2.3480-01 5.7573-01 3.5331-01-2.5820-01-6.2269-02 9.3969-02-1.8799-02-1.4473-02
 5.0996-02-1.0682-02-4.5712-02 2.1315-02 3.3389-02-2.9412-02-1.1073-02 2.5298-02
 1.4660-03-1.7401-02 1.1225-02 6.8096-03
SINE COEFFICIENTS
 8.6203-01-3.6890-01 3.4241-01 1.6036-01-9.3801-02-6.2005-02 7.3885-02-3.2233-02
-5.3739-03 5.0061-02-7.2993-03-3.3801-02 2.9456-02 1.4261-02-2.7769-02-2.3983-03
 1.4743-02-1.3688-02-1.4836-02 1.0967-02
SPAN 2  CHORD 3        STEADY=  1.1670+00
COSINE COEFFICIENTS
 3.6153-02 4.3770-01 2.3800-01-1.0792-01 9.4786-04 2.6809-02-1.6809-02-4.4114-03
 1.6007-02-9.9723-03-1.6766-02 1.2961-02 1.8404-02-5.6004-03-7.7983-03 3.0648-03
 5.3206-03 2.5373-04-1.0030-03 5.2031-04
SINE COEFFICIENTS
 1.6513-01-2.9152-01 1.3482-01 1.0499-01-2.7083-02-3.9884-02 3.3466-02-1.0066-02
-1.9905-03 1.3157-02 5.3144-04-7.0695-03 1.0855-02 1.0771-02-5.1551-03 9.8706-04
 4.2771-03-3.6736-03-8.4999-04 2.6145-03
SPAN 2  CHORD 4        STEADY=  3.3049-01
COSINE COEFFICIENTS
-1.8622-02 1.6918-01 9.1091-02-2.8325-02-7.6945-04-1.9190-03-4.6766-03 1.5585-04
 9.3526-04-5.1824-03-1.3972-03 4.5376-03 2.3754-03-3.2999-03 3.6815-04 2.3122-03
 1.2046-04-3.8169-04-1.1685-03 8.4820-04
SINE COEFFICIENTS
 5.8196-02-1.2590-01 5.3145-02 3.4403-02-7.5195-03-1.4167-02 9.6493-03-6.1310-03
 1.5729-03 2.1637-03-1.2349-03 4.8798-04 4.1079-03 6.3155-04-2.6168-03 9.1563-05
 2.8008-04 6.4710-04-4.5661-04-1.5777-03
SPAN 2  CHORD 5        STEADY= -2.6795-01
COSINE COEFFICIENTS
-9.0928-02 5.3081-02 6.3878-03 3.8282-03 1.0424-02-4.7782-03-3.6000-03 3.7117-04
-7.6841-04-3.2737-03 2.5626-05 9.8857-04-1.1964-03 2.0172-03 1.9327-03-2.4409-03
-6.8230-04 2.5071-03-2.0619-03-7.8069-04
SINE COEFFICIENTS
-2.6342-01-5.0281-02-1.2248-02-3.8144-03-3.2948-03-1.6939-03 2.3997-03-1.3287-03
 9.0472-04-2.6847-04-1.6263-03 1.4245-03-6.8683-04-1.6138-03 2.9647-03 1.0073-03
-2.7757-03 6.4360-04 2.4381-03-1.3857-03
SPAN 3  CHORD 1        STEADY=  3.9477+00
COSINE COEFFICIENTS
 1.4573+00 1.8760+00 6.0962-01-8.1466-02 1.0923-01 1.3432-01 5.8176-02 7.7133-02
-1.0972-02 2.2718-02 3.3884-02 2.7090-03 3.1234-03 3.5242-02 2.9696-02-1.3755-02
-1.1970-02 2.7746-02 2.7679-02-1.4920-02
SINE COEFFICIENTS
-9.6755-01-7.3308-01 4.2895-01-3.3845-02 4.6161-02-7.9354-02 1.3480-02 5.7115-02
-1.9792-02-5.3176-02 1.8256-02 4.5262-02-6.5775-03-3.0035-02 2.1128-02 1.8440-02
-2.4255-03-2.5806-02 1.1606-02 1.3369-02
SPAN 3  CHORD 2        STEADY=  2.1446+00
COSINE COEFFICIENTS
 7.3822-01 1.0241+00 5.4965-01-2.0762-01 9.0279-03 2.8066-02-1.1768-01-1.1330-02
-7.2869-03-3.4481-02-1.4295-02-2.2984-02-4.6823-02-3.2670-03 9.0476-03-2.9111-03
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TABLE III - Continued

```
 2.7507-03-6.5170-03 7.2571-03 5.5234-03
SINE COEFFICIENTS
 1.5152-01-4.4647-01 5.0507-01 2.7870-01 4.5368-02 6.9165-02 6.9216-02-1.3809-02
 2.2589-02 6.2651-04 1.5174-02 4.7598-02-1.0175-02-4.2581-02-1.8025-03-2.5457-03
-1.3614-03-8.3647-03-1.6346-02 8.2629-03
SPAN 3  CHORD 3        STEADY=  2.2804+00
COSINE COEFFICIENTS
 6.1680-01-1.2348-02 3.9052-02-6.0965-02 7.4262-03 9.0132-02 1.7467-01-4.6664-02
-1.7756-01 5.1089-02 8.7836-03-1.1369-01 7.3430-02 1.1755-01-6.1647-02-3.3923-02
 2.8435-02-4.6226-02-1.1991-02 5.7733-02
SINE COEFFICIENTS
 1.1709+00-5.0245-02-4.9753-02-3.6881-02-4.9472-02-1.7701-01 8.1153-02 2.1381-01
-5.3480-02-1.1039-01 9.3143-02-3.4402-02-1.2929-01 7.3801-02 8.0348-02-4.4807-02
 1.4083-02 1.7196-02-6.8245-02-1.2460-02
SPAN 3  CHORD 4        STEADY= -1.4001-01
COSINE COEFFICIENTS
 5.5032-02 2.0813-01 8.7312-02-2.4308-02 4.4836-03-1.1123-02-1.2558-02 1.0460-02
 5.4560-03-9.2544-03-8.1840-03 3.4579-03 3.8295-03-7.9206-04-5.8464-04-9.2843-04
 4.3369-05 3.3211-03 1.3424-03-1.0044-03
SINE COEFFICIENTS
-2.6103-01-1.2826-01 5.4065-02 2.1888-02-6.2990-03-2.1009-02-4.1003-03-8.8084-03
 3.9808-03 1.9786-03-1.8983-04 2.8918-03 2.7337-03-1.7692-04-1.1628-03 5.4819-04
-2.2209-03-1.5380-03-8.2616-04 6.6094-04
SPAN 3  CHORD 5        STEADY= -4.8059-01
COSINE COEFFICIENTS
-1.3731-01 4.7593-02 1.3981-02 1.0150-02 1.1324-02-1.6981-03-5.0781-03-2.0810-03
 2.1089-03-1.5039-03-3.4366-03 1.3553-03 2.5296-03-2.0094-03 1.2725-04 5.6646-04
 2.0742-03-8.2560-04-9.2299-04 9.0082-04
SINE COEFFICIENTS
-2.3050-01-6.6663-02-1.1055-02-7.9756-03-6.5035-03-2.5249-04 4.2678-03-3.3653-03
-3.8953-03 1.2221-03 9.2712-04-2.4018-03 7.9446-04 3.1504-04-1.5066-03-3.9539-04
 1.2188-04 1.6670-03-1.1400-03-1.2270-03
SPAN 4  CHORD 1        STEADY=  4.4730+00
COSINE COEFFICIENTS
 2.2124+00 1.6766+00 4.0374-01-1.0878-01 1.3650-01 3.8835-02-1.1552-02 9.0071-02
 3.1705-03-3.6407-02-3.3682-02-1.1912-02 3.6912-02 8.4938-03-3.5871-02-3.3531-02
 6.3298-04 2.1237-02 7.5846-03-1.2069-02
SINE COEFFICIENTS
-1.2938+00-1.2318+00 9.3319-02-1.6722-01-5.9175-02-1.1554-01-2.2913-02 3.6477-02
 1.7852-02-2.9279-02 3.5526-03-1.6263-02-2.1724-02-6.5509-03-4.2524-03-3.2260-03
-1.3391-02-4.3201-03 8.4565-04 1.3863-02
SPAN 4  CHORD 2        STEADY=  2.4903+00
COSINE COEFFICIENTS
 1.0869+00 5.6502-01 1.6195-01-1.2968-01 6.7293-02-3.1824-02-3.9358-02 3.9588-02
-5.2406-02-2.9767-02-1.3611-02-1.4594-02 1.5777-02 6.9624-03-9.1203-03-1.3455-02
 5.6250-03 5.0716-03-8.4739-03-7.8347-03
SINE COEFFICIENTS
-5.8867-02-3.2947-01 2.5851-01 2.8052-02 2.9276-02 3.1602-02 2.7717-02 6.7440-02
 4.0111-02-1.5245-02 2.4809-02 3.5184-03-8.9099-03-4.0205-03-4.7786-04-5.8072-03
-1.0331-02 3.4637-03-1.3455-03 4.1274-03
SPAN 4  CHORD 3        STEADY=  1.0400+00
COSINE COEFFICIENTS
 6.1414-01 3.7395-01 1.3600-01-2.1139-01-6.5824-02 5.2319-02-4.5384-02 3.4188-02
 9.3080-02-2.8612-02-5.6458-04 8.9210-02 3.8439-04-6.8960-03 8.4203-03-8.6770-02
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TABLE III - Continued

```
-5.3650-02 3.3209-03-3.2928-02 2.7447-02
SINE COEFFICIENTS
-5.1180-01-2.4457-01 1.8967-01 5.8926-02-1.6454-01-8.2182-02 5.2447-03-9.2250-02
 1.2958-02 4.5735-02-4.6743-02 3.0599-02 7.0379-02 3.2832-03 5.4466-02 4.2759-02
-5.9248-02-2.5733-02-3.8993-02-6.2326-02
SPAN 4   CHORD 4        STEADY=  4.2532-01
COSINE COEFFICIENTS
 3.8372-03 2.3594-03 6.8401-04 3.1364-03 9.5454-04-1.0804-03-9.7846-04 9.9977-04
-2.8806-04 1.9272-04 7.0838-04-2.7169-04-6.3612-04-6.9644-04 4.7466-04-7.8850-04
-3.9293-04-6.4698-04 8.2807-04 1.1297-04
SINE COEFFICIENTS
-8.7697-03-5.7226-03-2.9085-03-1.6156-03 1.1959-03 8.7107-04-7.3408-05-3.5323-04
 6.5734-05-1.2464-03 2.2869-04 5.1171-04 4.1387-04 7.1668-04 5.7159-04-5.1241-04
-5.3240-05-8.4274-04-2.2428-03-3.8887-04
SPAN 4   CHORD 5        STEADY= -1.5631-01
COSINE COEFFICIENTS
-4.5418-02-5.3395-03-5.8310-03 1.1256-02-7.0341-03-1.9194-02 3.0985-03 9.3085-03
 3.3523-03-3.1391-03-3.2925-03 2.8919-03 2.5976-03 2.0959-03 5.5866-04-1.4674-03
-3.6510-03 3.7935-04-3.7308-03-2.3899-03
SINE COEFFICIENTS
-1.8804-02-3.6265-02-2.0300-02-1.0678-02-1.7750-03-1.5052-02-7.0313-03-4.0521-03
 4.0975-03 5.4174-03 6.1051-04 3.6358-03 2.9539-03 2.5404-03 2.4111-03 2.5101-03
 2.4219-03 2.5176-03 5.0466-04-2.3442-03
SPAN 5   CHORD 1        STEADY=  3.2696+00
COSINE COEFFICIENTS
 2.0046+00 1.6480+00 5.0288-01 9.2904-02 2.6187-01 8.9191-02-4.3607-02 4.8412-03
-5.1710-02-5.3762-02-3.5641-02-2.6560-03 5.9304-02 5.9131-02 2.7158-02-3.7486-03
-4.6606-03-1.5988-03-2.8828-03-1.9307-02
SINE COEFFICIENTS
-1.8906+00-1.3664+00-1.9498-01-3.9211-01-2.2437-01-1.8561-01-4.5884-02 3.8437-02
 4.5989-02 4.0322-02 8.4455-02 5.8197-02 2.3810-02-1.2610-02-1.8651-02-2.0619-02
-2.6703-02-2.0395-02-1.1260-02 1.6719-02
SPAN 5   CHORD 2        STEADY=  8.7676-01
COSINE COEFFICIENTS
 9.3373-01 5.3204-01-1.9656-01-1.4380-01 4.3690-02-1.7998-01-1.9903-01-3.1042-02
-6.8466-02-8.2286-02-2.0858-02 5.4094-02 7.9998-02 4.0636-02 6.3773-02 7.9425-02
 2.9458-02 1.4448-02 4.6239-02 1.2019-02
SINE COEFFICIENTS
-7.7377-01 1.2583-01 2.3973-01-8.2824-02 9.5909-02 6.7154-02-6.8356-02-6.7138-02
-3.7856-02-9.8347-02-1.1197-01-8.9397-02-2.8279-02-3.3386-02-4.7123-02 1.4854-02
 4.4799-02 7.3189-03 1.8814-02 6.2283-02
SPAN 5   CHORD 3        STEADY= -7.6026-01
COSINE COEFFICIENTS
-4.1755-02 1.3583-01-1.6262-01 2.4107-02 7.3984-02 1.1230-01 2.0041-01 9.4305-02
-7.3158-03 5.3467-03-6.4675-02-9.5011-02-5.8451-02-5.4029-02-1.2369-02 3.9352-02
 6.6915-02 5.2314-02 2.5150-02 1.0242-02
SINE COEFFICIENTS
-1.2903+00-1.9380-01-1.8661-01-2.4445-01-1.3266-01-1.7970-01 1.0200-02 1.4386-01
 7.4502-02 7.1004-02 9.6561-02 2.4676-02-1.4186-02-5.0168-02-8.7040-02-6.4507-02
-1.5850-02 2.1642-02 2.9820-02 3.8326-02
SPAN 5   CHORD 4        STEADY= -9.5285-01
COSINE COEFFICIENTS
-4.6599-01-1.3663-01 8.1952-03 1.2890-01 5.6554-02-7.5664-02-5.3357-02 2.2944-02
 1.1758-02-3.5168-03 1.4669-04 8.8109-04 9.2646-03 9.4173-03 9.6026-03-4.3020-03
```

TABLE III - Concluded

```
-1.2860-02-1.0323-03-1.8734-03 2.0387-03
SINE COEFFICIENTS
-6.0449-01-2.1478-01-1.8502-01-5.9861-02 6.2156-02 2.1512-02-3.1247-02-3.5712-02
 3.6384-03 2.1206-03 2.0071-03 6.3677-03 2.7045-03 7.1605-04 6.6618-03 1.4635-02
-9.1894-04-7.3571-03-7.0105-03-3.3858-03
SPAN 5  CHORD 5        STEADY= -4.9909-01
COSINE COEFFICIENTS
-1.6881-01-9.3818-02-7.4127-03 2.1447-02 8.8081-05-2.3368-02-7.9206-03 5.8653-03
 9.3403-03-8.4737-03-7.1763-03 1.1066-03 3.6834-03 2.3429-03 1.4201-04-3.6788-04
-3.8353-04 1.1121-04-4.3679-03 3.5202-04
SINE COEFFICIENTS
-1.9641-02 2.9487-04-2.5624-02-1.0691-02 1.0132-02 3.3772-04-7.0948-03-8.4056-03
 1.0416-02 9.2963-03-4.4621-03-3.9652-03-1.4713-03-1.9142-07-1.2930-03 2.5565-03
 7.6226-04 6.9681-04 9.3474-04-1.7682-03
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TABLE IV. AERODYNAMIC DATA - 190 KNOTS, HIGH WING LIFT

```
BURST NO. = 14              *** ROTOR NOISE PUNCHED OUTPUT ***
BLADE PITCH HARMONICS
 7.3659+00 7.7624-01-9.9936+00  (COLLECTIVE,LONGITUDINAL,LATERAL RESPECTIVELY)
DIFFERENTIAL PRESSURE HARMONICS FOR 5 CHORD STATIONS AT EACH OF THE 5 SPANS
(MEASURING FROM THE LEADING EDGE AND THE BLADE ROOT RESPECTIVELY).
SPAN 1  CHORD 1        STEADY=  5.9205-01
COSINE COEFFICIENTS
-1.1092+00 3.7894-01 1.2676-01 1.9292-02-2.4620-01-8.7885-02 1.0097-02 7.5569-03
 1.5930-02 2.6000-03 1.4514-02 5.7394-03-3.4756-03 5.1775-03 8.7267-04 1.7984-02
 5.8849-03 1.0126-02-6.6541-03 6.6514-03-3.2098-03 1.0023-02-2.1409-03 3.5913-03
-1.0522-04 4.9785-04-6.1852-03-6.3346-03-1.9788-03 5.1453-03
SINE COEFFICIENTS
 5.4531-01-7.0990-01 5.6707-01 2.3961-01 3.1231-01-6.9963-02 6.1151-02 1.1693-02
 6.3858-02 1.0946-02 1.3549-02 2.2950-02 1.7013-02 2.5837-02 9.8661-03 1.7026-02
 3.1695-03 1.5587-03-4.2063-03-3.1824-04 6.6649-03 4.7874-03 3.5404-03-1.2738-03
 1.5484-03 1.8845-03-6.3261-03 3.2078-03 2.4385-03 3.6978-03
SPAN 1  CHORD 2        STEADY=  4.0097-01
COSINE COEFFICIENTS
-5.2888-01 1.8620-01 7.8860-02 2.6946-02-1.3494-01-5.8417-02 5.0237-03 5.7601-03
 9.2963-03-4.4291-03 6.7866-03 7.2854-03-9.3669-04 2.9635-03-3.2412-04 1.3492-02
 4.0305-03 6.7497-03-3.5582-03 4.4371-03-1.6112-03 5.2975-04 7.7845-03 4.6149-03
 5.3258-04-2.1223-03-4.1166-03-4.4023-05 3.0555-03 2.4908-03
SINE COEFFICIENTS
 4.2705-01-4.0600-01 2.40?3-01 1.1736-01 1.5525-01-4.1245-02 2.1318-02 2.8000-03
 3.6046-02 8.1194-03 7.0502-03 3.3689-03 5.9771-03 1.1927-02 7.3949-03 4.1143-03
-6.4226-04-5.4549-03-4.2440-03 1.8592-03 7.5572-03 3.4441-03 5.5315-03-1.7016-03
-1.4456-03-6.5278-04-3.0445-04 4.0344-03 4.6491-03 2.1749-03
SPAN 1  CHORD 3        STEADY=  1.1834-01
COSINE COEFFICIENTS
-4.0501-01 1.3706-01 2.9035-02 8.7241-03-8.2347-02-3.5454-02-4.9942-03 2.6369-03
 4.0610-03-6.1684-03-1.5777-03 2.4145-03 2.2073-03-1.1484-03 1.2048-03 8.1059-03
 1.5689-03 5.0734-03-3.1936-03-1.0793-03-3.2493-03 1.0338-03 5.1476-03 3.3996-03
 1.0909-03-1.6021-03-5.5738-03-1.2253-03 3.2016-04 1.0265-03
SINE COEFFICIENTS
 1.9633-01-3.2059-01 1.0153-01 3.6790-02 8.9439-02-2.1063-02 9.4480-03-1.0236-02
 1.7884-02 4.1991-03 9.7496-03 1.4844-03 6.0488-03 8.0361-03 2.7450-03 5.9561-03
 1.4358-03-2.1399-03 9.4157-04 3.9441-03 5.4303-03 4.7064-03-6.9283-04-2.6877-03
 3.1202-04-3.0202-03-2.8659-03-2.8601-04 2.4263-05 2.0422-03
SPAN 1  CHORD 4        STEADY= -1.4574-01
COSINE COEFFICIENTS
-1.3201-01 1.0295-01 2.3644-02 2.9962-05-3.8687-02-1.0622-02 7.4292-03 8.1364-03
 2.0755-03-4.0245-03-1.4349-03-1.7920-04-1.1627-03-2.0665-03-1.1808-03 4.3881-04
-2.6975-04-4.6552-04-9.7649-04-7.1929-04-1.0118-03-4.9585-05 5.8038-04-3.7776-04
-2.2914-03-1.1773-03-1.0279-03 5.2196-04-1.4551-04 4.4730-04
SINE COEFFICIENTS
 2.0471-02-1.1959-01 1.1170-02 1.2697-02 3.4278-02-6.0969-03 1.9277-03-1.1109-02
 1.3394-03-7.5586-04 8.5642-04-1.0452-03 9.9844-04 2.2423-03 2.3552-04 3.8975-04
 5.2248-04 1.4560-03 1.4854-03 5.4297-04 9.5622-04-3.7803-04 4.3612-05-3.1506-04
-2.4010-04 3.1493-04 2.0592-03 8.1389-04 8.6179-04-1.3148-04
SPAN 1  CHORD 5        STEADY= -1.0891-01
COSINE COEFFICIENTS
-1.0064-02 5.6517-02-1.9021-02-2.4158-02 2.1138-02 7.0737-03-8.6781-03 5.6271-03
 4.2463-04-4.2321-04 4.1592-03 2.9554-03-1.5824-03 1.2488-03-4.4951-04-2.9779-04
-3.0160-04 7.9272-04-9.9096-04 1.0246-03 2.4585-03 5.5107-04 2.2953-03 2.8900-04
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TABLE IV - Continued

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-1.5427-03-1.5027-03-1.0592-03-1.8655-04 1.8243-04 1.8185-03
SINE COEFFICIENTS
 1.3627-01-5.2918-02-3.3094-02 2.0365-02 2.4154-02-1.3036-02-9.3428-04 2.7100-04
-2.7980-03 2.2211-03 1.7032-03-4.0139-03-1.9119-03-1.1066-04-1.1305-03-2.3026-04
 7.9131-04-2.7365-03 1.8956-03 1.0277-03 1.9916-03-1.8608-03-2.8597-04-1.7124-03
-1.7658-03-1.3767-04 4.3419-04 1.8591-03-1.1410-03-5.8921-04
SPAN 2  CHORD 1       STEADY=  1.4244+00
COSINE COEFFICIENTS
 2.9956-01 1.0035+00 4.6720-01 1.5415-02 3.2790-02 2.5974-02 6.6824-02 1.7145-02
 4.0161-02 1.2546-02 4.4857-03 1.0980-02 1.5690-02-6.9024-03-1.8112-03-9.8786-04
 2.2971-02-9.5181-03-1.2351-03 3.1615-03-3.4725-03-5.0504-03-1.6373-03 2.7803-03
 5.1115-03 1.0336-02 1.2809-02 1.0380-02 1.5119-03 1.1195-02
SINE COEFFICIENTS
-1.3758-02-4.2511-01 3.7117-01 2.3869-01 1.6788-01-1.2235-01-9.0834-03-1.4380-02
 3.3095-03 2.3464-02 1.6706-02 5.3233-03 1.0151-02 1.0406-02-6.9217-04-5.6517-03
 9.1592-03 9.1892-03-7.5701-03-5.4190-03 8.2407-03 2.7784-03-1.0752-02-2.2236-03
 1.0177-03-1.3142-02-5.0042-03-3.0536-03 1.4033-03 1.8800-03
SPAN 2  CHORD 2       STEADY=  1.3651+00
COSINE COEFFICIENTS
 3.3043-01 4.3460-01 2.5889-01-1.0717-01-8.0122-02-2.9214-02 4.1236-02 1.9813-02
 4.3497-02 2.9645-02 7.6557-03 1.8727-02 1.6503-03-1.3856-02 2.3657-03 7.8806-03
 1.5093-03-5.9124-03-3.1624-03 7.2054-03 6.1450-03 1.5556-03-7.2943-03 6.1819-03
-3.5908-04 1.0525-03-7.7967-03 6.1456-03-3.3546-03 3.8851-03
SINE COEFFICIENTS
 7.3059-01-1.3647-01 3.1341-01 2.3473-01 3.6269-02-1.4167-01-4.3919-02-3.5123-02
-1.2204-02 2.4422-02 1.6428-02 8.3888-03 2.4665-02-5.5523-04-1.0924-02-5.0013-04
 3.3436-03-8.7607-04 1.0304-03-2.2739-03-6.7580-04 8.9098-03-2.9253-03-3.0172-03
 2.0961-03 1.9189-03-3.6214-03-8.5636-03 4.5993-03 4.5695-03
SPAN 2  CHORD 3       STEADY=  6.1909-01
COSINE COEFFICIENTS
 6.2637-02 3.4599-01 2.1209-01 6.4571-03-4.1576-02-7.5662-02 3.8362-02 8.3290-02
 4.8343-02-4.7184-02-5.2616-02 1.8836-02 4.6485-02 8.6905-03-1.7689-02 3.2514-03
 1.3816-02-4.0958-04-1.2676-02-1.4293-02 1.3544-02 2.6793-02-6.6525-03-3.9897-02
-1.1357-02 4.1258-02 2.6828-02-3.8617-02-4.2903-02 3.4197-02
SINE COEFFICIENTS
 2.6038-02-2.1144-01 1.0880-01 1.6602-01 5.9203-02-1.0352-01-9.4883-02-1.9972-02
 6.6633-02 5.9494-02-2.7689-02-5.2311-02 3.0472-03 2.9551-02 4.1015-03-1.6996-02
-1.0318-03 1.4736-02 8.0598-03-1.3343-02-2.1750-02 1.0487-02 3.4573-02 2.7660-03
-4.3233-02-2.0804-02 3.9771-02 3.2678-02-3.6532-02-4.5663-02
SPAN 2  CHORD 4       STEADY=  1.0482-01
COSINE COEFFICIENTS
-2.5327-03 9.8922-02 5.3052-02 1.7226-02 1.7032-02-2.1161-02-6.1016-03-3.3690-04
 9.9655-03 2.6269-03-2.1662-03-1.0043-03 2.1720-03 4.8377-04 5.7733-04 2.0357-03
 2.3070-03 7.7249-04 4.4796-04-9.9652-04-2.4627-03-7.0862-04 5.4502-04-1.0030-03
-8.1584-04-3.3877-04-2.7650-05 1.5196-04 2.7045-05 1.0531-04
SINE COEFFICIENTS
 6.2049-02-7.7735-02 2.5258-02 2.2563-02 1.5739-02-8.2812-03-8.2322-03-1.3159-02
-1.5030-03 5.5504-03 3.2288-03-1.2799-03-2.5786-04-2.6862-04-2.0658-03-6.0850-04
-9.1970-04-1.5812-04 1.3922-03 1.9846-03-1.5833-04-1.6176-03-3.3993-05 1.1149-03
-2.1969-04-6.4973-04-4.1697-04 4.1901-04-6.1817-04 3.9668-05
SPAN 2  CHORD 5       STEADY= -3.2076-01
COSINE COEFFICIENTS
-9.9946-02 4.8361-02-3.5539-03 8.8840-03 1.0992-02-3.0762-03-1.4027-03-4.3179-03
-5.0066-04-2.2158-04-1.3428-03-1.8325-03 1.2443-03 1.3968-03 8.4772-04-7.1613-04
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TABLE IV - Continued

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-1.8096-03 5.9915-04 5.9113-04-2.3565-04-5.4596-04-8.2358-04 3.1053-04-7.5403-04
-6.7537-04-5.5229-05 1.7483-04 2.1693-04 2.9764-04-1.8471-04
SINE COEFFICIENTS
-2.9532-01-5.6861-02-2.5101-02-1.1171-02-6.0739-03 3.8057-03 1.1932-03-1.8923-03
-2.0723-03 8.5275-04 1.7492-03-9.8949-04-5.6545-04 2.8139-04 2.7291-04 1.2894-03
-1.3873-03-1.1736-03-9.3983-05 7.4090-04 3.5898-04-6.9814-04 1.2697-04 1.7925-04
-4.6710-04-6.1041-04-4.7605-04 3.5154-04 7.1876-04 2.7948-04
SPAN 3  CHORD 1        STEADY=  1.9283+00
COSINE COEFFICIENTS
 1.1882+00 1.1366+00 3.8892-01 9.4327-02 1.4671-01 7.8910-02 9.7748-02 6.2453-02
 2.8183-04-1.8406-02 2.4442-02 2.2441-02-1.0096-02-9.5425-03 8.0438-03 1.5813-02
-2.6176-04-2.5396-02-3.2375-03 5.4365-03-1.8469-03 2.4646-03 2.7695-04 3.7917-03
-3.0204-03 6.4301-03 2.1082-04 5.5414-03-5.1316-03-1.7453-03
SINE COEFFICIENTS
-5.8531-01-3.3270-01 3.7240-01 1.8169-01 2.4605-01-1.2003-01-8.3381-03 2.6927-02
 5.8302-02 2.1130-02 1.9570-02 3.0700-02 1.5902-02 8.1564-03 1.4315-03 1.2529-03
 2.4361-02-4.5814-03-1.2337-02 6.7773-04 1.2031-02 3.0368-03 4.8645-03-2.9378-03
-4.3385-03 9.9162-04-2.3190-03-1.4019-03 5.1409-03-7.3729-03
SPAN 3  CHORD 2        STEADY=  9.9698-01
COSINE COEFFICIENTS
 7.1923-01 7.2815-01 4.1630-01 1.4378-01 1.7579-01 2.0725-02-9.0374-03-6.1249-02
-8.4126-02-5.3817-02-2.1154-02-8.3086-03-4.4730-03 1.7068-03-1.1180-02-2.0665-03
-6.0177-03-2.8789-02-1.5249-02 6.1246-06-4.0101-03 1.4064-02 1.1505-02 2.4666-03
 6.4327-03-7.1387-04-4.3240-03-5.3469-05-2.8964-03-4.2548-03
SINE COEFFICIENTS
 5.9026-02-2.3492-01 2.8469-01 2.2463-01 2.4268-01 8.2463-02 1.0112-01 8.1815-02
 4.1146-02-3.9628-03-6.7198-03-1.0568-02-8.0497-03 5.6390-03 1.0267-02-3.6863-03
 1.2682-02-2.5617-03-1.6918-02-8.7228-03-1.0414-02-1.4481-02-2.3919-03-1.4781-03
 2.1947-03 1.3279-02 3.9690-03 3.9910-03 3.8827-03-6.2175-03
SPAN 3  CHORD 3        STEADY=  1.5269+00
COSINE COEFFICIENTS
 7.0328-01 9.3164-04 2.3186-02-1.3109-01-6.1976-02 5.7155-03 1.1417-01 6.5433-02
 3.9593-02 2.3993-02-3.8988-02-3.2143-02 5.2008-03-2.5707-02 8.9677-03 4.8137-02
-1.2731-02-2.8431-03 2.7276-02-2.4172-02-3.3318-03 1.0423-02-3.5625-02 9.1383-03
 2.0682-02-1.5171-02 2.1771-02 1.6770-02-2.2326-02 1.1512-02
SINE COEFFICIENTS
 1.1264+00 1.3649-01 1.5368-01 1.0274-01-5.6238-02-2.1651-01-7.1841-02 1.8418-02
 3.3435-02 6.0708-02 5.2343-02-2.6296-02-1.1419-02-7.3349-03-4.8166-02 9.8577-03
 2.6905-02-2.1288-02 1.9576-02 1.9623-02-2.2658-02 2.0435-02-2.4683-03-3.7349-02
 1.0269-02-2.6089-03-2.1133-02 2.9199-02 3.1139-03-1.5121-02
SPAN 3  CHORD 4        STEADY= -4.3107-01
COSINE COEFFICIENTS
 4.5497-02 1.0173-01 4.3542-02 4.7632-02 4.1557-02-4.3163-02-1.9350-02 1.1813-02
 9.3575-03 3.4356-03 1.3100-02-1.0310-04-1.3843-02-6.4280-04 1.0191-02-7.6302-04
-4.4395-03 1.5339-03 4.7982-03-4.8314-04-4.3994-03 1.5498-03 3.4346-03 1.9117-05
-3.6069-03-1.8819-03 1.8719-03 2.9796-03 8.3426-04-1.3434-03
SINE COEFFICIENTS
-2.2046-01-7.5074-02-6.8908-03 8.0060-04 4.3212-02-2.1020-03-2.9876-02-2.2225-02
 2.5283-03-3.5048-03 3.4249-03 1.5157-02-5.1279-04-1.4110-02-1.1317-03 6.1811-03
-1.6073-03-5.2370-03 9.4289-04 3.9665-03-1.3628-03-3.7482-03 1.2074-03 4.5978-03
 8.1017-04-3.0619-03-1.7611-03 9.1858-04 2.3491-03 4.7299-04
SPAN 3  CHORD 5        STEADY= -5.6483-01
COSINE COEFFICIENTS
-1.5787-01 3.5172-02 9.4862-03 2.0628-02 1.5273-02-5.9415-03-5.6621-03-1.9154-03
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TABLE IV - Continued

```
 2.8827-03-6.1842-04-7.2487-04 5.3754-04-1.0129-03-1.8472-03-2.5310-04 6.7923-04
 8.7823-04-1.7071-04 8.6745-04 2.7727-04 1.2659-03-1.1164-03 4.9867-04 3.3684-04
 3.2017-04-8.3752-04-6.8522-04-1.8678-04 5.3404-05-7.0096-04
SINE COEFFICIENTS
-2.3354-01-7.2560-02-2.3996-02-1.1372-02 1.4518-03 3.2455-03-4.0970-04-8.3734-03
-1.3775-03 9.7763-04-7.0524-04-4.6081-04 6.3883-04-7.0993-04-1.6764-03-1.3977-03
 1.0954-04 7.1569-04-5.3329-04-4.9668-04 5.8883-04-1.0802-05-5.1751-04 3.4999-04
-2.1479-04-1.8004-04-7.8608-04-9.3017-04-4.3195-04-1.6016-04
SPAN 4  CHORD 1       STEADY=  2.5395+00
COSINE COEFFICIENTS
 1.6948+00 1.2214+00 5.3055-01 2.3501-01 2.1768-01 7.4142-02 1.2629-01 1.3496-01
 7.8975-02 6.8779-03-3.1993-02-2.0592-02 1.3054-02 2.3328-02 4.0352-03-1.3557-02
-1.8118-02-1.9825-03 4.4313-03 8.2211-03 7.9420-05-2.2728-03 8.2944-04 2.0106-03
 4.0320-03 8.4848-05-3.9426-03-6.1908-03-4.2967-04 2.5257-03
SINE COEFFICIENTS
-6.4857-01-6.6813-01 2.4523-01 8.1241-02 6.8562-02-3.2978-01-1.8592-01-5.6154-02
 5.0346-02 4.2490-02 5.6733-03-3.0528-02-1.6895-02 6.7851-03 1.7506-02 5.6537-03
-1.4366-03-1.7365-02-1.7251-03 6.8988-03 6.3333-03 5.8950-03-4.9249-03-6.6672-03
 2.8474-03-4.6696-04 6.8746-04-2.3596-03-1.3911-03 1.9140-03
SPAN 4  CHORD 2       STEADY=  1.6192+00
COSINE COEFFICIENTS
 1.1089+00 3.6966-01 2.2724-01 4.7817-02 9.3752-02-1.2768-02 6.9707-02 9.1806-02
 8.5098-03 2.3400-03 8.3457-03-3.0945-02 8.7623-04 1.2024-02 7.5259-03 3.3788-03
-1.2839-02-9.6539-03 2.5663-03 7.7393-03 6.7605-03-6.6010-03-9.2521-03-3.7248-03
-2.3068-03 3.3538-03 5.8508-03-4.4952-03-5.0838-03 3.0355-04
SINE COEFFICIENTS
 1.5324-01-1.4461-01 2.0357-01 9.0670-02 4.5326-02-1.1125-01-6.6577-02 3.7140-02
 6.9763-02 2.2718-02 4.4121-02 2.1942-02-4.5173-03 1.4418-02 1.1145-02 1.4601-02
 1.0281-02-8.6809-03-2.6211-03 1.8978-03 8.0338-03 1.2988-02-1.4088-03-6.6827-03
-5.2064-03 1.1007-04 6.5092-03 7.9670-03-1.8613-03-3.4352-03
SPAN 4  CHORD 3       STEADY=  3.5062-01
COSINE COEFFICIENTS
 5.2712-01 3.5286-01 1.3326-01 3.8675-02 2.1634-02-8.8956-02 1.8658-02 7.7102-02
 1.0161-02 1.5839-02 3.5943-02-5.2973-03-1.3252-02-2.1414-02-1.4804-02-1.1993-02
-2.4504-02 8.3108-03 2.7843-02-3.1822-03 1.4313-02 7.8800-03-8.2391-03 1.8872-02
 6.5288-03 4.4606-03 2.5690-02-1.5932-03-3.7378-03-2.2275-03
SINE COEFFICIENTS
-6.7621-01-2.2824-01 8.1992-02 4.0352-02 4.5711-02-9.2793-02-1.1241-01-1.5497-02
 2.8994-02-1.1939-02 2.1519-02 3.9864-02 2.3138-02 1.1553-02-8.6169-03-2.8837-03
-1.7346-02-4.0474-02 1.3143-03 3.5308-03-1.1023-02 1.2480-02-1.0806-02-1.3648-02
 1.0972-02-9.2392-03 9.7518-03 2.3560-02 1.1399-02 1.9566-02
SPAN 4  CHORD 4       STEADY=  4.7686-01
COSINE COEFFICIENTS
 7.2836-03-1.4030-02-6.3946-03 9.0251-03 5.4112-03-2.7563-03-6.7600-04 2.4413-03
 6.0691-04-2.5502-03-1.6347-03-2.4199-04 4.1944-04-5.2580-04 1.2896-03 3.4351-04
-1.0796-03 2.2131-04 2.6993-04-6.7244-05 8.1144-04 1.5667-03 8.2389-05-3.9019-04
-6.9344-04-2.7250-04-8.0258-05 9.3499-04-1.5633-03 3.3935-04
SINE COEFFICIENTS
 9.1905-03 1.3623-03-1.3235-02-7.2224-03 4.4520-03 1.9363-03-2.3247-03-8.6906-04
 2.3374-03 1.7886-03-4.8156-04-2.2423-03-2.5468-04-3.0270-04 2.9245-04 1.4438-03
 1.2398-03-1.0428-03-4.2083-04-7.3243-05-6.5266-04-1.9615-03 8.6994-06 6.7578-04
 1.0320-03-3.4404-04-1.2678-03 1.3636-04-7.9807-05-2.2191-03
SPAN 4  CHORD 5       STEADY= -1.7720-01
COSINE COEFFICIENTS
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TABLE IV - Continued

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-3.5518-02 1.0354-02 3.7192-03-1.4406-02-1.4226-02 1.1942-02 3.1011-02-2.2319-02
-3.1891-02 1.3097-02 3.2654-02 5.3470-03-1.7622-02-1.0956-02 4.9314-03 6.7084-03
-1.2950-03-8.1775-03-3.8378-03 2.1579-03 1.8809-03 6.0225-04-5.9618-03-2.8831-03
-1.1184-03 2.1613-03 1.9445-04-1.4487-03-1.7254-03 7.8919-04
SINE COEFFICIENTS
-1.5425-04-4.7577-02-5.4914-03-8.1307-03-2.8578-02-2.2636-02 2.3222-02 3.2097-02
-2.1889-02-3.5946-02 7.5968-04 2.3624-02 9.5022-03-9.1984-03-1.1629-02 3.2664-03
 5.3687-03 2.0532-03-6.3862-03-4.4792-03 4.9634-04 1.5381-03-1.7088-04-2.0245-03
-6.7512-04-4.4414-04 1.3105-03-1.6094-03 9.6966-06-1.4077-03
SPAN 5  CHORD 1        STEADY=  1.3252+00
COSINE COEFFICIENTS
 1.3744+00 8.3109-01 2.7955-01 1.9060-01 2.3936-01 1.1634-01 8.9053-02 1.0434-01
 5.4139-02 2.0605-02 2.9940-03-5.1691-03 1.9904-02 2.3420-02 2.1410-02 1.1794-02
 3.3604-03 6.4799-03 1.0864-02 1.6390-02 1.3431-02 5.6630-03 5.5223-03-5.1150-03
 2.0848-03 3.5014-03-2.7080-04-3.5869-04-1.0904-02-2.7420-03
SINE COEFFICIENTS
-1.2131+00-7.7800-01-1.2900-02-9.5792-02-1.6068-02-2.9430-01-1.4468-01-4.6057-02
 2.4897-02 3.0128-02 9.4257-03 1.8999-03-1.8891-03 8.1237-03 2.2002-02 5.1906-03
 7.5223-03-1.4243-02-4.7082-03-3.2489-03 4.6512-03 4.3335-03 2.7716-04-5.8502-03
-3.6764-03-5.6522-03 1.7762-03-1.4926-03-6.7603-04 3.4418-04
SPAN 5  CHORD 2        STEADY= -1.3341-02
COSINE COEFFICIENTS
 6.7766-01 1.7051-01-7.8812-02 8.3113-02-4.5599-02-1.0362-02 1.5344-01 1.4265-01
 4.1942-02-3.5980-02 4.3165-03-2.6730-02-5.5302-02 6.8527-03-6.0010-03-5.8690-02
-2.1323-02 3.2276-02 3.4869-02 1.5094-02 3.4662-02 2.5166-02-2.0381-02-5.7755-03
 2.1206-02-7.7316-03-1.8334-02 2.8333-03-7.3561-04-1.3362-02
SINE COEFFICIENTS
-7.2447-01 5.3000-02-7.1130-02-2.6780-02-2.2497-03-2.9633-01-1.3171-01 2.3143-02
 1.0416-01 4.5124-02 1.7650-02 5.1142-02-3.8260-03-1.8230-02 3.6808-02-5.4174-03
-5.8376-02-4.5922-02-1.7798-03-2.2070-03-2.5088-03 3.4164-02 2.4565-02-1.7206-02
 6.2808-03 2.3406-02-5.2153-03-8.8479-03 8.5420-03-2.4387-03
SPAN 5  CHORD 3        STEADY= -1.2741+00
COSINE COEFFICIENTS
-3.7221-02-2.6930-02-2.0753-01-1.6595-02-1.0484-01 4.3271-02 9.3921-02 2.8150-02
 1.3183-01 1.0539-01 8.6595-02 6.9231-02 1.5056-02 2.0992-02-1.9658-02-3.2926-02
-2.8132-02-7.7783-02-3.9366-02-1.5943-02-2.8272-02 2.0524-02 5.7485-03 4.2987-03
 4.1286-02 1.3444-02 1.8407-02 3.6722-02-1.2449-02-1.7611-02
SINE COEFFICIENTS
-1.2143+00-3.3394-02-1.9603-01-1.3286-01-1.5594-01-2.9382-01-7.3698-02-1.1054-01
-7.6734-02 1.7260-02 1.8319-02 7.4277-02 6.8265-02 6.0271-02 7.6626-02 3.1130-02
 4.5632-02 1.4426-02-4.2425-02-1.5982-02-4.0473-02-4.0364-02-6.8373-03-3.7750-02
-1.2205-02 1.2488-02-8.9722-03 2.7688-02 3.9791-02 3.7977-03
SPAN 5  CHORD 4        STEADY= -1.2315+00
COSINE COEFFICIENTS
-2.3090-01-7.1232-01-2.7225-01 9.3458-02 9.1156-03 1.4412-01 1.7086-01-1.4592-01
-6.6842-02 1.4411-01-1.0191-01-2.3800-01 8.7375-02 1.9948-01-8.5358-04-3.8604-02
-4.7926-04-5.7869-02-3.7402-03 8.0536-02-2.9466-02-7.8823-02 6.1829-02 6.1483-02
-6.2011-02-3.6967-02 3.8438-02 5.2662-03-1.9851-02 1.2952-02
SINE COEFFICIENTS
 2.3777-01 1.0857-01-4.3212-01-2.0939-01-1.1057-01-1.4465-01 1.7174-01 1.3867-01
-1.2665-01 3.2654-02 1.8677-01-1.1762-01-2.4000-01 4.1041-02 1.2278-01 7.6424-03
 2.1290-02 6.0304-03-7.5717-02 8.0039-03 8.1411-02-4.9413-02-7.2649-02 6.7222-02
 5.0775-02-5.2316-02-1.9122-02 3.0202-02-5.3814-03-1.2569-02
SPAN 5  CHORD 5        STEADY= -5.3763-01
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TABLE IV - Concluded

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COSINE COEFFICIENTS
-1.3989-01-1.2869-01-1.1491-03 2.9616-02 2.3204-02-2.6640-02-2.1158-02-1.4166-02
 2.0075-03 8.2553-03 3.6105-04 1.7726-03-5.0883-03-9.7381-03 1.7093-03 9.8029-03
 8.5202-03 2.8063-04-8.3328-03-4.8777-03 2.4237-03 2.6320-03 1.8109-04-2.0310-03
-3.8506-03-3.8739-04 1.8818-03 1.2356-03 1.3745-03-1.9532-03
SINE COEFFICIENTS
 3.1735-02-9.4362-03-5.6778-02-2.7915-02 2.0070-02 3.1321-02 4.1310-03-1.0028-02
-1.3381-02 9.7944-04-1.3507-03 2.3835-03 7.1141-03-5.6995-03-1.1554-02-3.2537-03
 6.2177-03 8.4199-03 2.3555-03-5.8442-03-3.1161-03-2.8413-05 1.1708-03 3.2890-03
 1.4009-04-3.1773-03-1.4323-03 7.3384-05 1.8550-03 3.6477-04
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TABLE V. AERODYNAMIC DATA - 190 KNOTS, LOW WING LIFT

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BURST NO. = 15              *** ROTOR NOISE PUNCHED OUTPUT ***
BLADE PITCH HARMONICS
 8.7258+00 2.4432+00-1.0150+01  (COLLECTIVE,LONGITUDINAL,LATERAL RESPECTIVELY)
DIFFERENTIAL PRESSURE HARMONICS FOR 5 CHORD STATIONS AT EACH OF THE 5 SPANS
(MEASURING FROM THE LEADING EDGE AND THE BLADE ROOT RESPECTIVELY).
SPAN 1  CHORD 1         STEADY=  8.0769-01
COSINE COEFFICIENTS
-1.1134+00 6.4077-01 1.8691-01-4.1122-02-2.9480-01-5.5690-02-3.7574-03 9.5882-03
-1.4204-02 1.1748-02 1.0607-02 1.6340-02-1.0120-02 6.5922-03-1.7981-02 1.2968-02
-1.1787-02 1.2284-02-7.7771-03 1.5188-02-1.6986-02 5.9656-03-1.4349-02 7.7399-03
-6.3117-03-2.3671-03-3.6248-03 2.3520-03-8.5207-03-9.3426-04
SINE COEFFICIENTS
 5.8842-01-7.3428-01 6.9683-01 3.1083-01 2.0935-01-9.3836-02 4.2661-02 2.8467-02
 4.2642-02 2.1323-02 1.8214-02 1.7329-02 6.9319-04 7.5742-03-2.8357-03 2.2695-02
 4.2410-03 8.0878-03-6.7673-03-4.2954-03-6.1894-04-2.4895-03 3.4188-03 2.8803-03
 4.4382-05-5.4978-03-4.7333-03-4.1582-03 9.4605-04-2.3959-03
SPAN 1  CHORD 2         STEADY=  4.8316-01
COSINE COEFFICIENTS
-5.3825-01 3.1270-01 1.0887-01-3.7806-03-1.6201-01-3.6508-02 6.5061-03 2.3246-04
-6.7215-03 4.5989-03 6.0824-03 1.4642-02-2.7479-03 1.2593-03-7.3210-03 7.2962-03
-1.7260-03 4.6678-03-3.5766-03-4.2078-04-8.9340-03-5.7652-03-2.8022-03 1.8793-03
-2.4965-04-1.3487-03-2.4050-03-3.4351-04 1.3777-03-3.7923-03
SINE COEFFICIENTS
 4.6056-01-4.2795-01 2.9857-01 1.5808-01 1.0490-01-5.3918-02 1.2538-02 6.0939-03
 2.6068-02 9.9186-03 8.1266-03 3.3121-03-1.6229-03 1.1116-03 1.8492-03 8.8230-03
 8.6815-03 1.4923-03-8.3689-04-9.0449-03 2.5571-03-4.3020-03 3.7729-03 7.0545-04
 2.0443-03-3.5715-03-2.5575-03-3.5601-03-6.0785-07-3.1131-04
SPAN 1  CHORD 3         STEADY=  1.6066-01
COSINE COEFFICIENTS
-4.1150-01 2.1753-01 4.7432-02 1.2165-03-1.0268-01-2.8761-02 2.8202-04 4.5927-03
-2.0239-04 2.1633-03-6.2227-04 8.7815-03-4.2586-04-2.5371-03-5.3987-03 4.4825-04
 4.9592-04 2.1774-03-4.1253-04 1.3055-03-3.7660-03-3.8585-03 5.6557-05-9.8998-04
 1.1994-03-9.4583-04 4.1472-03-1.0726-03 1.4064-03-2.4873-03
SINE COEFFICIENTS
 2.1777-01-3.3563-01 1.2390-01 5.9402-02 6.3716-02-2.3987-02 6.4126-03-6.8486-03
 1.4064-02 2.8298-03 6.1818-03 2.3779-04 2.8532-04-1.8224-03 1.3427-03 4.5055-03
 5.3075-03 1.2020-03-7.6852-04-5.6302-03-2.0456-04-4.7471-03 2.1006-03 2.0213-03
 3.5174-03-1.0481-03-1.3572-03 6.6258-05-2.0892-05 2.0236-04
SPAN 1  CHORD 4         STEADY= -1.4388-01
COSINE COEFFICIENTS
-1.3211-01 1.3549-01 3.0274-02-6.2082-03-4.7233-02-9.7812-03 8.3374-03 1.0714-02
 1.5437-03-1.4745-03-5.4786-04 7.9377-05-2.5249-03-2.9680-03-1.4050-03-5.0821-04
-1.2375-03-1.7280-03-7.4311-04-1.2904-03 7.0151-05-3.7986-04 7.0809-04-7.3315-04
 4.2255-04-6.1148-04-1.6539-04 1.0043-04-1.0119-06 9.5893-04
SINE COEFFICIENTS
 3.5496-02-1.2725-01 1.7817-02 1.7381-02 2.4745-02-4.5426-03 2.6711-03-7.6519-03
 9.3710-04-9.6942-04-1.7554-03-1.4147-03 9.9581-04 5.1468-04-1.0303-03 3.9579-04
 7.5885-04 1.5040-03 1.3179-03-1.9765-04 4.4318-04-7.3097-04 6.4040-04 1.2601-04
-4.0131-04 8.5349-05 3.6242-04 3.1432-04-6.2912-05-5.2342-04
SPAN 1  CHORD 5         STEADY= -1.1489-01
COSINE COEFFICIENTS
-6.8425-03 6.6866-02-2.2185-02-2.6464-02 2.1017-02 6.8628-03-1.2518-02 9.0503-03
 3.4124-03-1.5522-03 4.3302-03 2.7934-03-2.5496-03 3.2918-04-4.2519-04-1.3029-03
 7.3109-04 2.2378-03-8.1722-04-1.2307-03 5.7861-04-8.1638-04 1.4204-03-5.7190-04
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TABLE V - Continued

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 1.7234-03-1.0535-03 1.3421-03-6.3078-04 1.4565-03 9.2671-04
SINE COEFFICIENTS
 1.4211-01-5.7838-02-3.8396-02 2.1166-02 2.4944-02-1.4408-02-1.6421-03 5.1322-03
-4.5512-03 2.7695-03 1.2096-03-4.5297-03-2.3897-03 9.1876-04-1.1237-03 4.9567-04
 1.0323-03-2.4421-03 2.5129-04 9.0860-06 1.6919-03-1.8166-03 2.3492-03-2.3184-04
-4.9442-04-6.2188-05-7.9785-04 8.2320-05-1.3070-03 1.8153-03
SPAN 2  CHORD 1        STEADY=  2.2206+00
COSINE COEFFICIENTS
 3.8341-01 1.6176+00 5.3511-01-1.8562-01-1.2826-02 7.6743-02 3.6892-02 3.1061-02
 1.7333-02-2.2430-03-2.8412-02 8.6601-03 1.5447-02-1.3769-02-5.6939-04 8.2564-03
-9.2021-03-1.1104-02 1.0349-02 8.4559-03-3.5712-03-9.5292-03 1.0806-02-4.4861-03
 5.1955-03-6.3346-04-5.1197-03-1.2199-02-2.5807-03-8.1563-03
SINE COEFFICIENTS
-2.0540-02-5.3365-01 6.5573-01 1.5871-01 1.1257-01-8.2364-02 5.8972-03 8.7293-03
 2.5071-02 4.2065-02 1.3247-03-8.7135-03 2.2249-02 1.2009-02-8.5024-03 1.7224-03
 4.4417-04-1.3199-02 1.7907-03 1.1260-02-5.8279-03-1.3755-02-2.5902-03-4.7061-03
-1.4061-03-6.7170-03 1.1563-03-4.7603-03-5.0116-03 4.3223-03
SPAN 2  CHORD 2        STEADY=  1.8390+00
COSINE COEFFICIENTS
 2.7435-01 7.1804-01 3.0500-01-3.0164-01-7.8615-02 6.4871-02 3.9388-02 3.6986-02
 4.5326-02 1.9452-02-2.0918-02-6.0593-03 2.9183-03-1.2903-02-6.4608-03 1.5715-02
-5.1868-03-1.2629-02 1.6846-02 9.1966-03-1.1878-02-5.0529-04 7.4973-03-7.0341-03
-2.1101-03 2.8846-03 1.9899-03 1.0763-04 1.2717-03-1.4544-03
SINE COEFFICIENTS
 8.2238-01-2.5731-01 4.9040-01 1.7640-01-6.8479-02-1.2908-01-1.9829-02-9.0823-03
 1.1863-02 4.6107-02 2.4735-02-1.6300-03 9.9345-03 7.0459-03-1.1921-02-3.3949-03
 1.2576-02-1.5271-02-1.2327-02 1.4501-02 6.4699-03-7.0475-03 4.3484-03 2.6685-03
-8.1091-03-3.2989-03-1.0117-03-9.4675-04-2.8550-03 1.1593-03
SPAN 2  CHORD 3        STEADY=  8.8643-01
COSINE COEFFICIENTS
 8.2863-02 5.1760-01 2.2454-01-9.7242-02-2.2535-02-5.9805-03 3.6426-02 6.8824-02
 4.2712-04-5.1568-02-1.1492-02 3.7915-02 9.3074-03-1.7455-02-8.8262-04 1.3134-02
 7.0103-03-2.1180-02-2.3415-02 2.7413-02 5.1069-02-3.2886-02-7.7498-02 1.8604-02
 9.9549-02 1.3350-02-1.0429-01-4.9870-02 8.9322-02 7.8406-02
SINE COEFFICIENTS
 9.3614-02-2.4029-01 1.8921-01 1.1853-01 1.4841-02-9.1128-02-4.9314-02 1.8220-02
 6.4800-02 1.0411-02-4.0973-02-7.7177-03 2.7789-02 4.3616-03-9.9764-03-6.6735-04
 1.5991-02 1.3304-02-2.6726-02-3.6326-02 3.1320-02 6.3631-02-2.5849-02-8.9453-02
 1.7009-03 1.0452-01 3.0553-02-1.0264-01-6.5402-02 7.9633-02
SPAN 2  CHORD 4        STEADY=  1.8888-01
COSINE COEFFICIENTS
-3.4534-03 1.7668-01 7.3488-02-1.2040-02 7.7857-03-1.5210-02-4.7440-03 1.4124-02
 5.1512-03-2.1275-03-1.8888-03 2.0149-03 1.5722-05 1.4923-04 3.7936-03 5.9603-04
-1.1080-03-7.7192-04-1.1164-03-6.9703-04 1.1509-03 1.3361-03-1.3390-03-4.1917-04
 1.4910-03 7.4389-04 2.5555-05 2.1060-04-3.7174-04-2.4443-05
SINE COEFFICIENTS
 5.9238-02-1.0553-01 5.4801-02 2.6403-02 1.5268-02-1.9213-02-1.6096-02-1.0810-02
 8.6472-03 6.3940-03-2.6254-04-1.5252-03 4.0745-04 3.5091-04 1.6598-03 2.6955-03
-5.7970-04 4.8874-06 7.9387-04-2.0084-03-2.8737-03 2.5632-04 1.3845-03-3.7336-04
-1.8370-04 1.3211-04-6.6581-05 2.8639-04 1.9627-04-1.0650-03
SPAN 2  CHORD 5        STEADY= -3.1698-01
COSINE COEFFICIENTS
-6.7277-02 6.9951-02 7.5599-03 9.0269-03 1.3343-02-6.3237-03-4.4085-03 7.7280-04
 7.9724-04-9.1283-04-6.6537-04 6.8814-04-3.5045-04 3.5777-04 2.4527-04-2.2160-04
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TABLE V - Continued

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 1.5496-03 1.4238-03-7.7910-04-7.9337-04 6.2235-04 1.1324-03-1.7870-04 4.4357-04
 3.7514-04-1.4226-05-3.4691-04-2.8402-04-3.1044-04-2.0501-04
SINE COEFFICIENTS
-3.0663-01-5.1759-02-2.3536-02-6.2983-03 5.1751-04 1.0655-03-6.8638-04-4.6312-03
-4.1035-04-2.0967-04-6.2871-04-2.4118-04 2.1305-04 3.0733-04 8.3711-04 1.6756-04
-1.3354-03 1.5347-03 4.6728-04-1.1988-03-9.6755-04 9.2898-04 6.6893-04-5.1226-05
 3.6951-04 6.7010-04-3.2073-04-3.7967-04-7.7688-04-8.2175-04
SPAN 3  CHORD 1        STEADY=  2.9426+00
COSINE COEFFICIENTS
 1.5954+00 1.9041+00 5.2710-01 8.6687-02 1.4909-01 1.3359-01 1.4643-01 6.9714-02
-2.7504-02 1.9609-02 2.7494-02 1.4827-03 7.1150-03 1.3349-02 2.3262-02 6.3910-03
-1.0559-02 1.5033-02 1.7292-03 2.5727-03-6.8124-03 1.0606-03-7.7604-03-6.7043-03
-6.5090-03 1.4544-03 3.5098-03 4.1131-04 9.7685-03 9.5597-04
SINE COEFFICIENTS
-7.2772-01-4.6950-01 4.9443-01 2.2288-02 2.5408-01-1.1820-01-3.1211-02 9.0567-02
 4.0404-02 1.7777-02 3.4698-02 3.4575-02 1.5643-02 1.5431-02 1.2769-02 2.0958-02
-1.9399-03-6.3300-03 4.0086-03 7.0516-03 3.7262-03 3.7805-03 1.9986-03-2.6079-03
-2.1325-03 2.1416-03 3.6066-03 3.8799-03-1.7052-03 3.9701-03
SPAN 3  CHORD 2        STEADY=  1.5255+00
COSINE COEFFICIENTS
 8.1021-01 1.1108+00 4.9036-01-9.3373-03 1.2067-01-4.5506-02-8.0435-02-4.6314-02
-8.1519-02-1.1007-02 2.1581-02-2.5415-02-2.3764-02-1.5950-02-4.1590-02-7.6240-03
-9.7359-03-6.6866-03 2.1798-02 2.6785-04-1.0257-03 1.7644-04-1.3083-02-2.7484-03
 4.2035-04 3.2722-03 8.4976-03 1.8011-03 7.6620-03 6.2351-04
SINE COEFFICIENTS
 1.0062-01-3.4473-01 4.8267-01 2.1191-01 2.5463-01 9.4660-02 9.3753-03 3.6951-02
 4.5524-03-3.6108-02 2.4092-02 4.3951-02 5.9988-04 1.8649-02-8.3382-03-3.1967-02
-7.9336-03-3.1990-02-1.3880-02 1.5438-02-3.2620-03 3.3596-03 9.1268-04-7.9336-03
 4.9343-04-5.1056-03-4.8335-03-2.1406-03 1.5607-03 4.7523-03
SPAN 3  CHORD 3        STEADY=  1.8928+00
COSINE COEFFICIENTS
 6.5608-01 1.4603-01 8.6418-02-2.4026-01-6.0783-02 1.4015-01 1.1101-01 4.5428-02
 6.2665-02-5.6167-02-7.2419-02 4.1202-02-5.9037-02-8.4096-03 9.0807-02-5.4149-02
 1.3070-02 7.1228-02-8.0678-02 1.1778-02 1.8147-02-8.8626-02 6.0202-02 3.7074-02
-4.7184-02 6.1669-02-1.1469-02-6.2071-02 4.0549-02-2.3006-02
SINE COEFFICIENTS
 1.2267+00-2.0277-02 1.9338-01 5.8566-02-1.5474-01-2.2632-01 4.0150-03 2.4169-02
 6.8288-02 1.0404-01-3.9666-02 1.7255-04 3.0332-02-9.7691-02 1.8487-02 4.0304-02
-7.0354-02 5.9220-02 4.0098-02-5.6613-02 6.2556-02-2.9967-02-7.8734-02 6.4306-02
-1.9035-02-2.0453-02 7.7423-02-3.3604-02-2.0013-02 4.0370-02
SPAN 3  CHORD 4        STEADY= -3.4338-01
COSINE COEFFICIENTS
 8.9630-02 1.9079-01 6.8025-02 3.6556-02 2.6427-02-5.3083-02-6.6879-03 3.3751-02
-8.5843-04 3.8070-03 1.0175-02-1.4474-02-1.0721-02 1.3656-02 9.6569-03-9.1969-03
-3.9360-03 6.4786-03 1.3364-03-6.4871-03 1.8437-03 2.7142-03-2.0482-03-3.1625-03
 1.2101-03 3.5391-03 7.4776-04-2.4478-03-2.2961-03 5.5139-05
SINE COEFFICIENTS
-2.4979-01-1.0120-01 1.5502-02 4.3437-03 5.6234-02-2.4633-02-5.3337-02-6.4750-03
 1.4076-02-3.8817-03 1.2689-02 1.3935-02-1.4704-02-8.8935-03 1.2053-02 5.9070-03
-7.4171-03-3.3672-03 7.4124-03 5.5821-04-5.2145-03 1.5013-03 3.3568-03-1.0585-03
-3.8142-03-6.3028-04 3.0115-03 1.8897-03-8.5067-04-2.7189-03
SPAN 3  CHORD 5        STEADY= -5.6261-01
COSINE COEFFICIENTS
-1.3343-01 6.1401-02 1.6806-02 2.1756-02 1.6956-02-9.9214-03-9.7516-03 4.2868-03
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TABLE V - Continued

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 3.3945-03-1.2980-03-5.4740-04 1.0509-03-2.7367-04-4.1639-04 1.7454-03 1.4019-03
-8.3967-04-1.6992-03-3.4803-04 1.5441-03-1.3775-04-9.8145-04 1.8625-04 4.7829-04
 2.1312-04-1.1496-03 9.3764-05 5.3389-04-4.7108-04-6.0202-04
SINE COEFFICIENTS
-2.5832-01-7.1914-02-1.8747-02-6.9777-03 7.4332-03 2.2040-03-4.8522-03-8.6787-03
 1.7669-03 1.4045-03-6.7739-04 6.7524-04 3.6375-04-1.1914-03-1.1401-03 1.3873-03
 8.1489-04-6.5024-05-8.2604-04 3.7676-04 6.7295-04-3.8440-04-1.1499-03 1.7499-04
 9.9116-05-2.5486-04-9.0857-04 3.0908-04 9.7376-04-1.4035-04
SPAN 4  CHORD 1        STEADY=  3.5339+00
COSINE COEFFICIENTS
 2.2656+00 1.9037+00 5.5554-01 1.6351-01 1.9191-01 9.7532-02 1.1967-01 6.9432-02
-4.4631-02-7.0732-02-6.0376-02-8.2362-03 2.5821-02 4.4967-03-9.2719-03-1.5568-02
-2.6468-03 1.9655-02 8.0796-03-1.0725-02-1.2047-02-6.2956-03 1.0820-04 1.6493-03
-4.0213-03-5.4987-03 2.9456-03 6.8686-03 7.0836-03 1.0014-03
SINE COEFFICIENTS
-9.6203-01-9.9005-01 1.8747-01-1.3139-01 1.3529-02-3.7547-01-1.9154-01 3.6235-02
 8.3293-02 4.5926-02-2.5212-03-2.2157-02 1.6279-02 2.2950-02 2.1340-02-8.2484-03
-2.6488-02-2.0325-02 8.0193-03 4.4540-03 1.1444-03-7.4277-03-2.8773-03 3.7774-03
 7.7518-03-4.1293-04-5.1876-03-1.0675-03-1.3150-03-3.5077-03
SPAN 4  CHORD 2        STEADY=  2.0424+00
COSINE COEFFICIENTS
 1.1899+00 6.2772-01 1.7425-01-3.1210-02 8.2831-02-3.1412-02 7.9291-02 4.5110-02
-5.5483-02-1.1648-02-2.2010-02-2.3502-02 1.2679-02-3.6067-03-1.3538-02-1.5444-02
-9.2817-03-2.8320-03 1.1235-02-2.6179-03-1.2966-02-6.5792-03 4.0521-03 1.2138-02
-1.6805-03-9.0779-03-3.1299-03-5.7972-03 3.1478-03 3.5970-03
SINE COEFFICIENTS
 5.9827-02-2.8953-01 2.3783-01-1.2761-02 6.4036-02-1.2800-01-6.1006-02 1.0040-01
 5.2727-02 1.4006-02 3.5818-02 1.6829-04 1.0701-02 2.4572-02 2.0732-02 1.2704-03
-1.3629-03-9.9378-03 3.5416-04 1.1273-02 3.5172-03-1.1877-02-9.9167-03 1.7015-04
 1.0813-02-1.1178-03-2.8924-03-7.3153-03-8.1751-03 2.8555-03
SPAN 4  CHORD 3        STEADY=  6.5385-01
COSINE COEFFICIENTS
 6.6036-01 5.3244-01 1.5786-01-6.5048-02 8.0086-03-7.9025-02 7.0333-03 1.0319-01
-3.6787-02-1.8464-02 4.0930-02-3.4257-02 1.3943-02 3.9920-02-3.8542-03 2.4491-02
-6.0690-03-2.5100-02 6.4859-03-3.7756-02-4.4044-03 2.0086-02-7.3703-03 2.9059-02
 8.9450-04-2.1013-02 2.5437-02-1.7372-02-6.1789-03 2.7143-02
SINE COEFFICIENTS
-6.4548-01-2.6336-01 1.8979-01 4.1436-02 8.2108-03-9.5311-02-1.3519-01 1.0180-02
 6.1659-02-4.6645-02 1.5314-02 1.7673-02-4.5354-02 1.7516-02 1.7030-02 8.9737-03
 4.3248-02-2.6570-03 1.3983-02 1.0074-02-4.0538-02 1.9271-03-7.7410-03-1.0777-02
 3.0564-02-1.5780-02 8.2426-04 1.9958-02-2.6530-02 1.0133-02
SPAN 4  CHORD 4        STEADY=  4.7173-01
COSINE COEFFICIENTS
 6.8484-03-1.0403-02-1.9389-03 9.0698-03 3.0363-03-2.8908-03 2.4368-04 1.5315-03
-9.3613-04-2.4760-03-1.4961-03 1.9305-03 1.3929-03-6.2853-04-5.6560-04-7.9620-04
-1.2595-03 4.9407-05 7.0567-04 2.9448-04-6.4378-04 1.0563-03 2.1030-04-1.1417-03
 6.3876-04 1.2585-04-1.1069-05-1.6779-04 1.3636-04-8.4137-05
SINE COEFFICIENTS
 5.0418-03-2.9039-03-1.1779-02-3.8463-03 4.1491-03 1.5391-04-1.6354-03 8.7613-04
 1.8724-03 1.9338-04-2.6207-03-2.1301-03 1.5012-03 2.3690-03-1.6287-04 2.7120-04
 2.4585-04-8.0887-04 3.0876-04 3.5882-04 5.5432-04-3.0693-04 2.4980-04 1.0955-03
-5.2854-05 1.7278-03-1.6238-04-1.0786-03-5.5265-05-4.1984-04
SPAN 4  CHORD 5        STEADY= -1.7215-01
COSINE COEFFICIENTS
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TABLE V - Continued

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-4.1927-02 6.8289-04 4.3250-03 4.8093-03-1.1756-04 4.3594-03 1.4178-02-2.4937-02
-1.4775-02 2.6489-02 2.2596-02-1.2366-02-1.6755-02 4.8756-03 1.5609-02-6.1584-04
-6.9615-03 1.3225-03 7.2628-03 2.8388-03-6.3856-04 1.7227-03 3.3148-03 1.2343-03
-5.8438-04 2.7182-04-1.8737-03 3.0534-04 2.3473-03 1.0244-04
SINE COEFFICIENTS
-3.1349-03-5.2792-02-2.1870-02-1.0611-02-1.8395-02-1.4476-02 2.1410-02 1.1990-02
-2.7272-02-1.7901-02 2.1994-02 2.2226-02-8.9346-03-1.4311-02 1.1913-03 1.1064-02
-1.1900-04-5.9227-03-2.4309-03 3.6801-03-3.0439-04-5.5335-04 8.6642-04 1.7491-03
 4.4627-04 1.4551-03-8.0058-05-2.0458-03 4.6437-04 2.4917-03
SPAN 5  CHORD 1        STEADY=  2.3216+00
COSINE COEFFICIENTS
 2.0426+00 1.6767+00 5.6372-01 3.4264-01 3.8742-01 2.4628-01 1.6999-01 9.8110-02
-1.8072-02-5.4133-02-7.0909-02-6.8556-02-4.7707-02-4.4455-02-3.8304-02-3.5446-02
-1.2823-02 1.8703-02 2.2037-02 2.6876-02 2.2448-02 2.3687-02 2.1124-02 1.9995-02
 1.2402-02 4.0600-03 1.1118-04-8.3074-03-7.6933-03-1.0589-02
SINE COEFFICIENTS
-1.5204+00-1.1047+00-9.3220-02-3.0691-01-8.1409-02-3.5562-01-2.0971-01-3.3080-02
-9.2192-03-8.8153-03-1.5981-02-2.5114-02 1.4466-02 1.9538-02 3.9991-02 2.9120-02
 1.1727-02 1.3767-02 2.5268-02 2.5593-02 1.9563-02 6.4351-03-6.1080-03-6.0173-03
-3.9283-03-1.0326-02-1.1748-02-1.9285-02-1.4186-02-1.1566-02
SPAN 5  CHORD 2        STEADY=  4.4398-01
COSINE COEFFICIENTS
 9.4442-01 4.4327-01-3.5205-02 8.3848-04-1.1862-01-6.2561-02 8.3655-02-3.5979-04
-1.0616-01-4.8867-02 1.2524-02-2.7896-03 1.7988-02 7.0725-02 1.2479-02-1.3345-02
 6.5861-02 5.6994-02 5.4085-04 1.2906-02 1.4127-02-2.3523-02-1.4051-02 1.1274-02
-2.5682-02-3.8683-02-8.0224-03-1.3158-02-1.2181-02 5.1879-03
SINE COEFFICIENTS
-6.9744-01 4.7069-02 7.2320-02 4.3000-02 7.4443-02-2.5419-01-8.5808-02 6.8506-02
 2.3007-03-7.8690-02-5.0360-02-3.0676-02-5.9143-02-1.5830-02 4.1357-02-3.4061-02
-3.0740-02 4.2329-02 3.5833-02 1.2488-02 3.9289-02 2.9709-02-4.1989-03 1.6326-02
 3.2599-02-1.0029-02-1.6029-02-5.6940-03-2.0720-02-1.7363-02
SPAN 5  CHORD 3        STEADY= -1.0767+00
COSINE COEFFICIENTS
 8.6138-02 9.1685-02-1.3430-01 2.0655-02-1.3790-02 1.2360-01 1.2516-01 7.8328-02
 1.2803-01 8.0228-02 2.1086-02-2.9243-02-4.5945-02-4.6832-02-8.2297-02-6.2384-02
-4.4417-02-1.8101-02 3.9637-02 3.5586-02 4.7213-02 4.8769-02 2.0276-02 2.7964-02
-8.2776-03-3.6242-02-2.7802-02-4.4898-02-2.6164-02 2.4237-03
SINE COEFFICIENTS
-1.2407+00-1.3457-01-2.2493-01-1.6435-01-1.5702-01-2.4399-01-3.2288-02-4.1056-02
 1.3218-02 9.6535-02 9.6804-02 8.7849-02 4.8328-02 4.5205-02 2.1647-02-3.1185-02
-3.9990-02-7.6559-02-5.7391-02-1.9725-02-1.5298-02 2.1991-02 2.5262-02 3.3387-02
 5.5798-02 2.1618-02 1.0908-02-4.5074-03-3.6731-02-3.1114-02
SPAN 5  CHORD 4        STEADY= -1.1982+00
COSINE COEFFICIENTS
-3.5465-01-8.1813-01-7.3010-02 3.1975-01-8.8407-03 7.2147-02 1.4548-01-1.5658-01
-1.0335-01 7.1585-02-9.9123-02-5.9922-02 2.1711-01 8.7342-02-1.4503-01-5.6581-02
 4.6835-02-1.5837-02-1.0576-03 3.2818-02-2.8106-02-6.6311-03 4.8376-02-2.3953-02
-4.5211-02 3.7358-02 3.2910-02-3.4351-02-1.6375-02 1.7953-02
SINE COEFFICIENTS
 2.5875-01-1.4142-01-6.4393-01-1.0152-01 5.1620-02-1.4375-01 1.5850-01 1.4064-01
-1.2041-01-7.4309-03 4.8749-02-1.8606-01-7.7442-02 1.9926-01 8.7304-02-8.6676-02
-1.6914-02 2.0601-02-3.1797-02 1.5052-02 2.2750-02-3.9584-02 1.1885-02 4.9410-02
-3.4657-02-4.1758-02 3.5711-02 2.4491-02-2.5353-02-6.2948-03
SPAN 5  CHORD 5        STEADY= -5.9347-01
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TABLE V - Concluded

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COSINE COEFFICIENTS
-1.6134-01-1.3220-01 1.3826-03 3.6067-02 1.2963-02-3.8695-02-2.3156-02-4.3012-03
 1.2629-02 5.9717-03 9.0565-04 5.4360-04-6.0439-03-7.4003-04 9.2382-03 6.1688-03
-1.8319-03-7.7409-03-1.2129-03 3.3105-03 1.0435-03 1.2205-03 8.2883-05-5.9439-04
 7.3427-04 2.8959-03 7.4559-04-2.0894-03-8.0692-04 1.5970-03
SINE COEFFICIENTS
 5.2420-03-2.7129-02-5.5790-02-1.4538-02 2.9601-02 1.7938-02-3.1215-03-2.0358-02
-9.1678-03 4.7081-03-8.9903-04 4.6979-03 4.4689-05-7.4202-03-3.1865-03 7.3678-03
 8.5627-03 1.5459-03-6.9852-03-1.9257-03 9.1735-04 8.4459-04 1.5435-04-7.5509-04
-2.6245-03-1.0075-04 2.3669-03 1.6999-03-1.5415-03-7.5286-04
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TABLE VI. AERODYNAMIC DATA - HOVER IGE

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BURST NO. = 20              *** ROTOR NOISE PUNCHED OUTPUT ***
BLADE PITCH HARMONICS
 7.8258+00 1.1503+00-2.5740-01  (COLLECTIVE,LONGITUDINAL,LATERAL RESPECTIVELY)
DIFFERENTIAL PRESSURE HARMONICS FOR 5 CHORD STATIONS AT EACH OF THE 5 SPANS
(MEASURING FROM THE LEADING EDGE AND THE BLADE ROOT RESPECTIVELY).
SPAN 1  CHORD 1         STEADY=  1.4433+00
COSINE COEFFICIENTS
-9.7192-03-5.9639-03-6.5223-02 5.6564-02 1.3127-02-2.7990-03-2.3523-02 1.8055-02
-1.2491-02 1.4598-03-4.7474-03 7.0054-03-1.2839-03-1.1573-03 7.1465-04 1.1426-03
 1.2120-04-2.6407-03 1.8924-03-1.7036-03-5.2691-04-1.7893-03 4.7205-03 1.3647-03
-7.9771-05 1.9676-04-1.1459-03 1.0729-03-2.6466-03 2.4336-03
SINE COEFFICIENTS
-1.0860-02 4.2926-02-2.0698-02 3.0354-02-2.0591-02-5.9400-03 4.6868-03-2.8436-03
-2.7297-03 7.0129-03-3.3665-03 5.0081-03-5.6727-03-6.9685-04 1.5584-03-1.2640-03
-2.9141-03 3.1088-03-1.5998-03 6.2845-04-2.0192-03 2.3837-03-6.9705-04-2.1749-03
 1.1440-03-2.0529-03-1.1579-03-4.8710-03 5.6479-03 9.4100-05
SPAN 1  CHORD 2         STEADY=  7.8065-01
COSINE COEFFICIENTS
 1.8890-02-1.3691-02-2.5972-02 2.6332-02 5.1353-03-7.6668-04-1.0815-02 1.0726-02
-5.0624-03 8.5002-04-2.3416-03 4.5532-03-1.1689-04-6.4062-04 1.4350-03 3.5783-04
 2.3674-03-1.1156-03-8.7474-04 6.3243-04 1.0548-03-1.1041-04 1.6489-03-1.0851-04
-4.4967-04-4.4625-04 4.7134-04-1.4413-04-1.3494-03-1.6044-03
SINE COEFFICIENTS
-5.2702-02 1.1373-03-9.9844-03 1.9914-02-6.7801-03-3.1725-03 3.1834-03 2.5320-03
 7.7719-04 2.2096-03-1.9760-03 3.8685-03-2.1607-03-7.1779-05-1.2810-03 1.4540-03
-4.8507-04 1.7209-04 7.1347-04 1.6503-03-1.4649-03 1.4966-04-1.9375-04-1.4473-03
 8.0212-04 7.1394-04 1.1472-04-4.4138-04-2.0638-04 2.0559-04
SPAN 1  CHORD 3         STEADY=  4.5688-01
COSINE COEFFICIENTS
 9.0797-03-2.3441-02-1.2051-02 2.4394-02 2.1495-03-8.1177-04-7.9146-03 9.5700-03
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 5.7613-04 1.0360-03 3.2072-04 8.0654-05-7.6929-04-1.7967-03-2.4353-03 9.0940-04
 2.6555-03 1.4248-05-1.7036-03-4.5194-04-8.3276-04 1.0223-03
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 5.4524-04-6.9595-05-6.1814-04 1.4234-04 4.4130-04-1.0446-04
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 9.0007-04-1.5920-04-8.3768-04 2.0420-04 1.5094-04-3.5990-04
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-7.9147-04 6.0410-03 2.1060-02-8.5809-03 4.5628-03 5.1149-03 6.2831-04-2.1773-03
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TABLE VI - Continued

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TABLE VI - Continued

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 4.1705-01-1.9426-01 3.5686-01 8.7233-02 3.4119-01-7.0811-02 1.7327-01 2.0558-01
-2.9579-02-8.0948-02 2.7524-02-1.4871-03-5.7388-04 5.4763-02 2.2441-02 2.9331-02
 9.8787-03 4.9686-02 7.2563-02-3.1075-02-7.1533-02 3.4661-03 4.3197-02 2.9916-02
-1.9224-02-2.8171-02 1.6913-02 2.4110-02-3.4057-02 3.8465-03
SINE COEFFICIENTS
 1.2462+00 1.1370+00 2.6048-01 1.0712-01 1.3294-01 1.0017-01 1.2114-02-8.7205-02
-4.6556-02 2.6927-02 3.6411-02 1.0374-01 2.6402-02-1.3085-02 1.5108-02-3.0507-02
-1.2530-02 3.6129-02-1.3072-02-5.5574-02-2.2028-02 3.4196-02 1.2766-02-4.5666-02
-3.9886-02 3.6591-02 3.2527-02-2.8278-03-7.7397-03 2.9914-02
SPAN 5  CHORD 2          STEADY=  1.8863+00
COSINE COEFFICIENTS
 6.8196-02-3.1396-02 1.6362-01 3.4565-02 1.0522-01-2.5942-02 5.2739-02 4.3929-02
-1.2618-02-2.2089-02 2.1241-03 3.0807-03-6.1963-04 1.5919-02 2.6837-03 7.1450-03
 6.0137-03 1.4196-02 1.8403-02-1.2403-02-1.9649-02 1.4783-03 1.2440-02 5.3596-03
-1.1513-02-5.0158-03 8.1928-03 5.6149-03-9.0597-03 4.5434-03
SINE COEFFICIENTS
 4.1127-01 3.7589-01 9.2801-02 2.0656-02-3.3232-05 2.2782-02-4.2592-03-3.2400-02
-1.1014-02 1.1785-02 1.5550-02 2.4987-02 4.8049-03-4.2221-03 1.2788-03-5.1071-03
-2.7636-03 6.1706-03-7.1995-03-1.6329-02-5.7494-04 1.0294-02-2.3746-03-1.3498-02
-8.6600-03 1.0006-02 8.6823-03-1.7402-03-1.6226-03 8.5620-03
SPAN 5  CHORD 3          STEADY= -3.4768-01
COSINE COEFFICIENTS
 2.0725-02-7.5038-03 1.0688-01 3.3554-02 5.2180-02-2.5882-02 2.1818-02 2.4646-02
-5.8588-03-6.5548-03 7.3608-03 4.0745-03-3.1236-04 7.3328-03 3.5906-03 5.9873-03
 4.1514-03 7.5627-03 9.6226-03-5.5366-03-8.7194-03 2.7186-03 4.0430-03 7.8431-04
-8.0711-03-2.8479-03 6.7962-03 3.6973-03-1.7881-03 3.8726-03
SINE COEFFICIENTS
 2.9537-01 2.6318-01 6.5311-02 5.5009-03-1.0856-02 1.5633-02 4.2224-03-9.7596-03
 2.1079-03 1.2202-02 8.7241-03 1.0239-02 3.9185-03-2.2352-03 1.8497-03-2.0469-03
-2.7370-03 1.0685-03-4.8319-03-5.4428-03 1.5987-03 2.3899-03-3.0597-03-7.4194-03
-2.9526-03 6.4700-03 4.2065-03-1.0523-03-1.7505-04 2.6191-03
SPAN 5  CHORD 4          STEADY= -1.2297+00
COSINE COEFFICIENTS
 1.1990-02-9.8206-04 3.4618-02 1.8900-02 1.1420-02-1.7852-02 4.0767-03 8.1591-03
-1.4421-03 1.4941-03 5.0727-03 2.8172-03-1.4228-03 2.8259-03 1.4485-03 3.5600-03
 1.1061-03 1.4954-03-4.5263-04-3.0201-03-1.4917-04 2.6571-03-1.0458-03-1.4243-03
-4.6322-03 5.6540-05 2.5394-03 1.1346-03 1.0195-03 1.7644-03
SINE COEFFICIENTS
 1.5066-01 1.2013-01 3.1194-02-1.4043-03-6.7568-03 4.5561-03 2.9857-03 5.5481-03
 6.9431-03 5.4926-03 2.3369-03 1.0737-03 1.7315-03 5.4355-04 2.1903-03 2.7878-04
-1.0480-03-3.5644-03-2.9630-03 3.1706-04 2.8753-03-1.3611-03-3.3145-03-3.4630-03
-3.0883-04 2.3253-03-4.6006-05-3.6237-04 9.8941-04-2.1456-03
SPAN 5  CHORD 5          STEADY= -6.4297-01
```

TABLE VI - Concluded

```
COSINE COEFFICIENTS
 2.9926-03 2.2005-03-4.8634-03 1.9972-03-4.1666-03-1.9537-03-3.9864-03-2.8134-03
 1.1079-03 3.3514-03 2.0212-03 2.6169-04-9.0851-04-1.1784-03-5.4933-04 2.1029-04
-3.8506-05-2.6009-04-2.0715-03-6.0588-04 1.2004-03 3.8149-04 4.3991-04-4.0285-04
-1.4459-03 3.1807-04 1.1580-04 1.4075-04 1.4981-03 1.4179-03
SINE COEFFICIENTS
-1.8457-03-1.8727-03-1.1444-04-1.0044-03-2.3780-03-1.9849-03-6.7478-04 3.7471-03
 3.6879-03 7.0451-05-6.3268-04-2.0633-03-5.6744-04 1.1653-03 8.1863-04 4.7887-04
-8.0376-04-2.0111-03-1.4353-03 1.9765-03 2.6780-03-4.2488-05-8.5037-04-1.1784-03
 3.4198-04 3.2124-04-3.0384-04-6.7212-05 1.0325-03-5.2506-04
```

TABLE VII. FLIGHT CONDITION TRIM PARAMETERS

FLIGHT CONDITION	CAS (knots)	Alt (feet)	δ_e (deg)	δ_f (deg)	Ω (rpm)	$\bar{L}_{wb}$ (lb)	T_{mr} (lb)	D_{mr} (lb)	T_1 (lb)	T_2 (lb)	θ (deg)
165 Knots HIGH WING LIFT	156	608	1	7.7	204	6640	11900	440	1730	1650	6.1
165 Knots LOW WING LIFT	162	602	1	- .5	204	540	18200	30	970	1210	4.1
190 Knots HIGH WING LIFT	183	610	1	2.5	204	6310	11900	890	2490	2280	8.3
190 Knots LOW WING LIFT	187	620	1	- .5	204	3860	14700	334	1820	1890	5.3
HOVER - IGE	0	30	1	- .5	204	0	18900	0	0	0	3.6

δ_e = Elevator deflection, positive for trailing edge down

δ_f = Flap deflection, positive for trailing edge down

$\bar{L}_{wb}$ = Total lift from wing/fuselage combination ($\pm$ 2000 lb)

T_{mr} = Main rotor thrust along drive shaft ($\pm$ 2000 lb)

D_{mr} = Main rotor drag parallel to flight path ($\pm$ 10%)

T_1 = Thrust from port J-60

T_2 = Thrust from starboard J-60

θ = Fuselage pitch attitude, positive for nose up

APPENDIX VI
ACOUSTIC TEST EQUIPMENT, TECHNIQUES, AND ACCURACY

GENERAL

Noise data were recorded on March 8, 1967, at the Bridgeport Airport, Stratford, Connecticut. The terrain was flat and free from obstacles which might affect noise propagation. Figure 21 shows the physical layout of the test area.

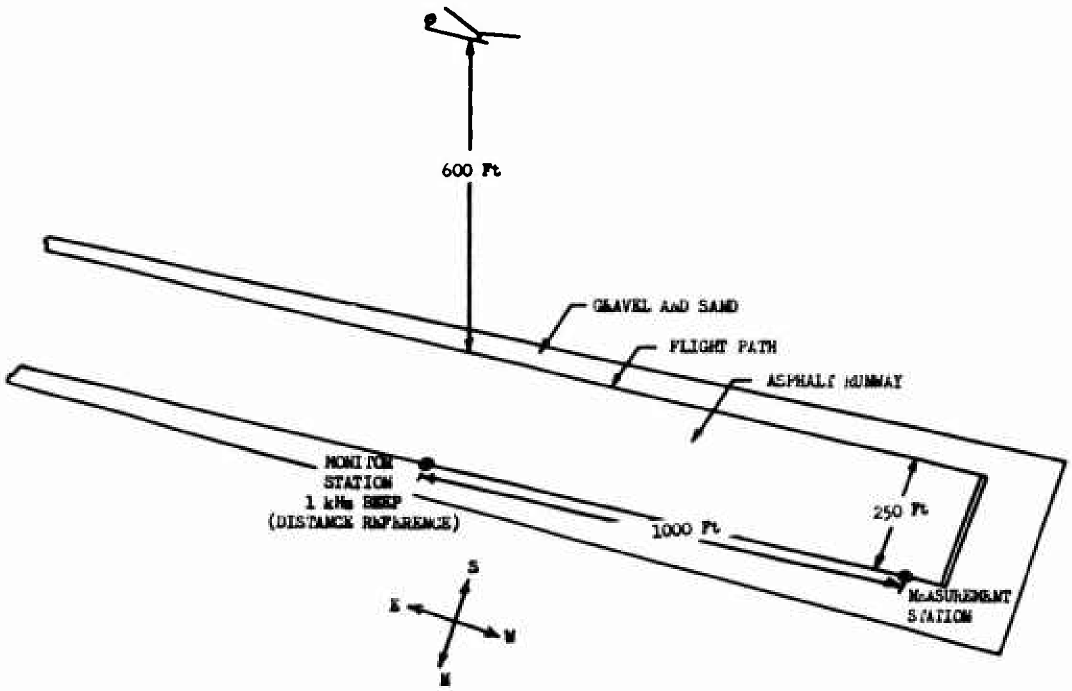

Figure 21. Schematic of Test Site.

The NH-3A proceeded from east to west at an altitude of 600 feet ± 50 feet for all forward flight cases, and a 1 kHz beep was placed on the tape when the aircraft was 1000 feet ahead of the noise measurement location. During hover, the main landing gear was approximately 10 feet above the ground. Winds at the noise measurement location were northerly, ranging from 0 to 5 knots throughout the test. The air temperature was 36 degrees Fahrenheit, the relative humidity was 72 percent and the sea level barometric pressure was 30.23 inches of mercury. Since the test was made at sunrise with low winds, the effect of atmospheric turbulence on sound propagation is considered to be neglible.

Noise data were recorded 250 feet north of the flight path, with the microphone 6 feet above the asphalt-surfaced runway. Noise reflection effects are not significant for the long wavelengths involved in the test. A 1-inch Bruel and Kjaer microphone with nose cone and wind screen was used in conjunction with a Bruel and Kjaer precision sound level meter (Type 2203) and a Nagra III tape recorder operating at 7.5 inches per second to

acquire noise data. The frequency response characteristics of these components and of the data processing equipment are known to within ± 0.5 dB. The combined acquisition/processing system is represented schematically in Figure 22.

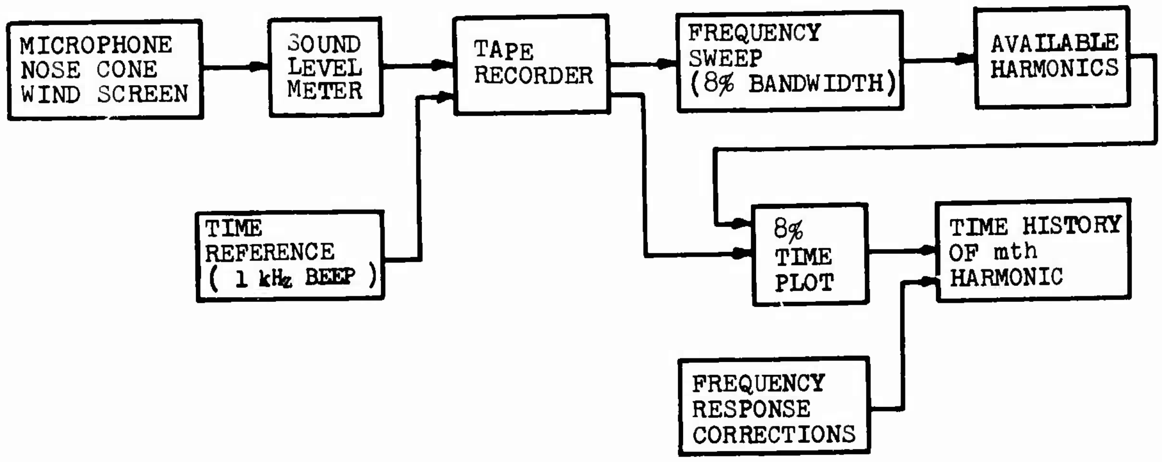

Figure 22. Noise Data Acquisition/Processing Block Diagram.

DATA REDUCTION

It was necessary to reduce the noise data by preparing narrow-bandwidth (8%) frequency spectra and amplitude versus time plots at selected frequencies. The spectra identified those harmonics which exceeded background noise, and the time plots at discrete frequencies compensated for the Doppler shift. The frequency shift exceeded 25 percent of the source frequency for the high-speed cases and precluded the use of even a 1/3 octave bandwidth filter. The time plots made with a bandwidth of 8% accommodated the Doppler shift in a point-by-point fashion without sacrificing resolution. Noise harmonics above the fourth were masked by the first harmonic of tail rotor rotational noise and by auxiliary propulsion jet engine noise for the forward flight cases.

The accuracy of the total data processing system is affected by the character of the noise as well as the method of processing. The noise exhibited both long-period and short-period variations. The long-period variation was a function of aircraft motion and noise radiation patterns. Short-period oscillations, however, appeared to be a 3 Hz (one per revolution) signal superposed upon the long-period amplitude variations. The 3 Hz oscillation was least pronounced for the fundamental and increased with harmonic order, to a peak-to-peak oscillation of as much as 6 dB. The presence of these oscillations together with the point-by-point method which was required to accommodate the Doppler shift produces a system amplitude accuracy of ± 3 dB.

The accuracy of the time reference that relates aircraft location to observer location is considerably better than that of Reference 1, but a possible

error of ± 0.5 second remains. Although the beep signal is transmitted instantaneously from the monitor station to the tape recorder 1000 feet away, there are still errors due to parallax and the reaction time of the monitor. An additional error is introduced when the reference time is noted on the time plots of the discrete frequencies. Available instrumentation did not permit simultaneous displays of the time reference signal and the recorded noise signal, thereby requiring a mark to be placed on the chart manually when the beep was heard through a monitoring speaker.

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13. ABSTRACT

The results of a measurement, prediction, and correlation study of rotational noise of the Sikorsky NH-3A compound helicopter are presented in Volume I of this report. The noise prediction computer program developed under the contract is documented in Volume II.

Measured and predicted levels correlated well for the first four harmonics of rotor noise during forward flight. Harmonic levels above the fourth could not be extracted from the measured noise data for correlation. Predicted levels grossly underestimated measured levels for low-altitude hover due to acoustic directionality and near-field effects, and due to aerodynamic ground effects.

Harmonics of differential pressure are tabulated in Volume I for up to 30 harmonics of revolution of the main rotor (30/rev) at each of 25 locations on a main rotor blade. Spanwise locations of the measured differential pressures are 40%, 75%, 85%, 95%, and 98%. Flight conditions are 165 knots, 190 knots, and hover IGE.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Rotational Noise Chordwise Pressure Distribution High-Frequency Airloads NH-3A Compound Helicopter Harmonics Acoustic Analysis						